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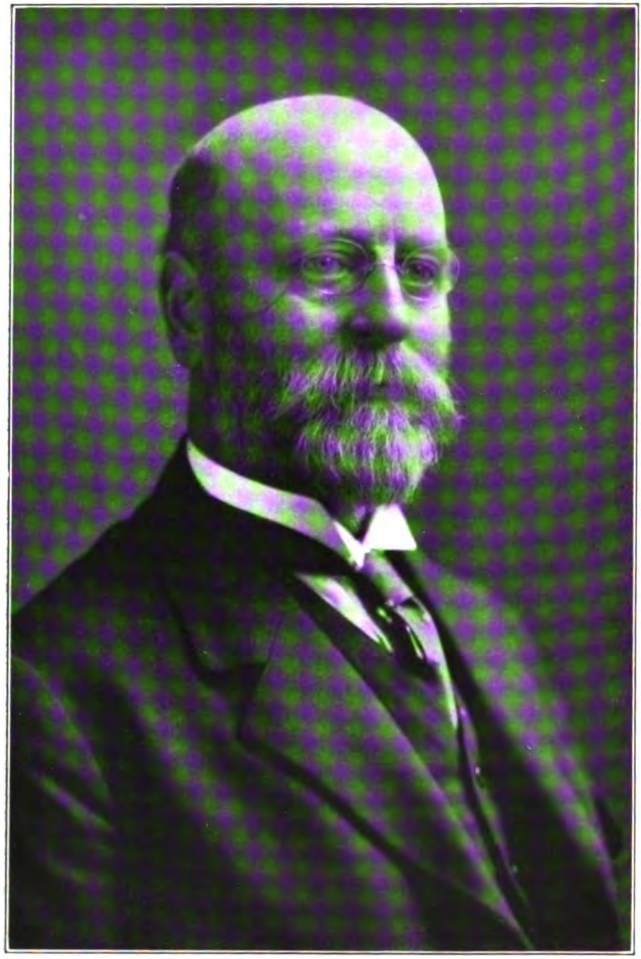

Yours faithfully

Ralph D. Moore

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TRANSACTIONS

OF THE

Institution of Engineers and Shipbuilders

IN SCOTLAND

INCORPORATED.

VOLUME LXXI

SEVENTY-FIRST SESSION, 1927-28

EDITED BY THE SECRETARY

GLASGOW:
PUBLISHED BY THE INSTITUTION AT
39 ELMBANK CRESCENT, C.2.

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Yours faithfully
Ralph

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The responsibility for the statements and opinions given in the following Papers and Discussions rests with the individual authors; the Institution as a body merely places them on record.

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MEMORANDUM OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

---

1. The Name of the Association is "THE INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND."

2. The Registered Office of the Association will be situate in Scotland.

3. The Objects for which the Association is established are:—

(1) The Incorporation of the present Institution of Engineers and Shipbuilders in Scotland, under the 30th and 31st Victoria, cap. cxxxi., and

(2) To facilitate the exchange of information and ideas amongst its Members, to place on record the results of experience elicited in discussion, and to promote the advancement of science and practice in Engineering and Shipbuilding.

(3) The doing of such other lawful things as are incidental or conducive to the attainments of the above objects.

4. The Income and Property of the Association, whencesoever derived, shall be applied solely towards the promotion of the objects of the Association, as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever, by way of profit, to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them.

Provided that nothing herein shall prevent the payment in good faith of remuneration to any Officers or Servants of the Association or to any Member of the Association, or other person, in return for any services rendered to the Association.

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5. The fourth paragraph of this Memorandum is a condition on which a Licence is granted by the Board of Trade to the Association, in pursuance of Section 23 of the "Companies Act, 1867." For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which may be duly observed by the Association.

6. If the Association acts in contravention of the fourth paragraph of this Memorandum, or of any such further Conditions, the liability of every Member of the Council of the Association, and also of every Member who has received any such dividend, bonus, or other profit as aforesaid, shall be unlimited.

7. Every Member of the Association undertakes to contribute to the Assets of the Association—in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the Debts and Liabilities of the Association, contracted before the time at which he ceases to be a Member, and of the Costs, Charges, and Expenses of winding up the same, and for the adjustment of the rights of the Contributaries among themselves—such amount as may be required, not exceeding Ten Pounds, or, in case of his liability becoming unlimited, such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

WE, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association:—

Names, Addresses, and Description of Subscribers—

DAVID ROWAN, 217 Elliot Street, Glasgow, Engineer.
W. J. MACQUORN RANKINE, C.E., LL.D., etc., 59 St. Vincent St., Glasgow.
M. R. COSTELLOE, 26 Granville Street, Glasgow, Measuring Surveyor.
BENJAMIN CONNOR, 17 Scott Street, Garnethill, Engineer.
JAMES DEAS, 16 Robertson Street, Glasgow, Civil Engineer.
JAMES M. GALE, 23 Miller Street, Glasgow, Civil Engineer.
W. MONTGOMERIE NEILSON, C.E., Hyde Park Locomotive Works, Glasgow.

Dated the Twelfth day of July, Eighteen Hundred and Seventy-One.

ROBERT ROSS, of Glasgow, Solicitor, Witness to the above signatures.

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NOTE.—By Special Resolution passed on 2nd October, 1902, and confirmed on 20th October, 1902, the Articles of Association dated 12th July, 1871, as modified and altered in 1873 and 1880, were annulled, and the following Articles of Association (with the exception of Articles Nos. 23, 25, and 27) were substituted, and they were registered with the Registrar of Joint-Stock Companies on 28th October, 1902.

By Special Resolution passed on 20th March, 1906, and confirmed on 17th April, 1906, the Articles Nos. 23, 25, and 27 of the Articles registered on 28th October, 1902, were cancelled, and the Articles Nos. 23, 25, and 27 below were substituted. This Resolution was lodged with the Registrar of Joint-Stock Companies on 28th April, 1906.

By Special Resolutions passed on 30th March, 1920, and confirmed on 20th April, 1920, the Articles Nos. 46 and 48 of the Articles registered on 28th October, 1902, were cancelled, and the Articles Nos. 46 and 48 below were substituted. These Resolutions were lodged with the Registrar of Joint-Stock Companies on 30th April, 1920.

ARTICLES OF ASSOCIATION

OF THE

INSTITUTION OF ENGINEERS AND SHIPBUILDERS IN SCOTLAND.

SECTION I.—PRELIMINARY.

1. For the purpose of registration, the number of Members of the Institution is declared unlimited.

2. These Articles shall be construed with reference to the provisions of the Companies Acts, 1862 to 1900; and terms used in these Articles shall be taken as having the same respective meanings as they have when used in those Acts.

3. The Objects of the Institution are those set forth in the Memorandum of Association. Objects of the Institution.

SECTION II.—CONSTITUTION.

4. The Institution shall consist of Members, Associate Members, Associates, Students, and Honorary Members. Constitution.

5. Candidates for admission as Members shall be persons not under 25 years of age, who have been educated as Engineers or Shipbuilders and have occupied a responsible position in connection with the Practice or Science of Engineering or Shipbuilding. Who may be Members.

6. Candidates for admission as Associate Members shall be persons not under 22 years of age, who have Who may be Associate Members.

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been educated as Engineers or Shipbuilders and are engaged in the Practice or Science of Engineering or Shipbuilding.

Who may be Associates.

7. Candidates for admission as Associates shall be such persons, not included in the classes enumerated in the two preceding Articles, who, not being under 25 years of age, are considered by the Council eligible on account of their scientific attainments, or are considered by the Council qualified by knowledge bearing on Engineering Science or Practice.

Who may be Students.

8. Candidates for admission as Students shall be persons not under 18 years of age who are engaged in study or employment with a view to qualifying themselves as Engineers or Shipbuilders. Before attaining the age of 25 years they must apply for election as Members or Associate Members if they desire to remain connected with the Institution. They may not continue to be Students after attaining the age of 25 years.

Who may be Hon. Members.

9. Honorary Members shall be such distinguished persons as the Council shall recommend and the Institution shall appoint. The number of Honorary Members shall not exceed Twelve.

Members, etc., under former Articles of Association.

10. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Members, Associates, or Honorary Members, and whose subscriptions are not more than two years in arrear at that date, shall become Members, Associates, and Honorary Members respectively within the meaning of these Articles, and that without procedure of any kind on the part of such persons.

Graduates under former Articles of Association.

11. All persons whose names shall on 30th April, 1902, be on the Roll of the Institution under the former Articles of Association as Graduates, and whose subscriptions are not more than two years in arrear at that date, shall be considered and treated as Students within the meaning of these Articles,

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and shall have the privileges, and be subject to the regulations affecting Students; and, notwithstanding the terms of Article 8 hereof, such Graduates as are over 25 years of age shall be allowed to remain as Students for one year from and after 30th April, 1902, but no longer.

Abbreviated Titles of Members, etc.

12. The abbreviated distinctive titles for indicating the connection with the Institution shall be the following, viz.—For Members, M.I.E.S.; for Associate Members, A.M.I.E.S.; for Associates, A.I.E.S.; for Students, S.I.E.S.; and for Honorary Members Hon. M.I.E.S.

Candidates, how recommended and elected.

13. Every Candidate for Admission as a Member, Associate Member, Associate, or Student of the Institution, shall obtain the recommendation of at least three Members, such recommendation and the relative undertaking by the Candidate being according to Form A contained in the Appendix. Such recommendation and undertaking shall be lodged with the Secretary, and the Council shall consider the same at their first meeting thereafter, and if they approve the recommendation shall be mentioned in the notice calling the next General Meeting of the Institution; and then, unless a ballot be demanded by at least five persons entitled to vote, the Candidate shall be declared elected. If a ballot be taken he shall be admitted if three-fifths of the votes are favourable; Members only being entitled to vote. The proposal for transferring any person from the Class of Students to the Classes of Associate Members or Members, or from the Class of Associate Members to the Class of Members, shall be according to Form B contained in the Appendix, and this form shall be subscribed by at least three Members and delivered to the Secretary for the consideration of the Council who shall, if they think fit, make the proposed transfer.

14. The granting of Honorary Membership to

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Honorary Members, how elected.

any person may be proposed at any Council meeting, and, if the Council, after consideration at their next meeting, approve of the proposal, intimation thereof shall be given by the Secretary in the circular calling the next General Meeting of the Institution. At that meeting, unless a ballot be demanded by at least five persons entitled to vote, the person proposed shall be declared elected. If a ballot be taken then the person proposed shall be admitted if four-fifths of the votes are favourable; Members only being entitled to vote.

Members, etc., formally admitted.

15. Every person duly elected or admitted as a Member, Associate Member, Associate, Student, or Honorary Member shall be notified in writing of his election or admission by the Secretary. At the first meeting of the Institution held thereafter at which he is present, he shall be introduced according to the ensuing form, viz.—The President or the Chairman of the meeting, addressing him by name, shall say: "As President (or Chairman of this meeting) of the Institution of Engineers and Shipbuilders in Scotland, I introduce you as a Member (or Associate Member or Associate or Student or Honorary Member as the case way be)." Thereafter the new Member, Associate Member, Associate, Student, or Honorary Member shall sign the Roll of Members, etc., to be kept by the Secretary, and on making payment of any fees or subscriptions due he shall be entitled to receive a diploma. The diploma shall be signed by the President and the Secretary.

Diploma.

Rejected candidates not to be noticed in Minutes—wish of Honorary Members to be obtained before being balloted for.

16. If any person proposed for admission into the Institution be not approved by the Council, or be rejected on being balloted for, no notice shall be taken of the proposal in the Minutes of the General Meetings, and such person shall not be proposed again for admission until after the expiry of one year from the date of such disapproval or rejection. Before the meeting of Council for considering any

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proposal to grant Honorary Membership, it shall be ascertained from any person proposed to be made an Honorary Member whether he will accept the honour, no notice being taken of the proposal in the Minutes unless he is elected.

Section III.—MANAGEMENT AND OFFICE-BEARERS.

Council. Management by.

17. The Direction and Management of the affairs of the Institution shall be confided to a Council, which shall consist of a President, six Vice-Presidents, and eighteen Councillors. Of the eighteen Councillors, not more than three may be Associates, the remainder being Members. Five Members of Council shall constitute a quorum.

Constitution of Council—five a quorum.

Who may be President.

18. Members only shall be eligible for election as President. The President shall preside over all meetings of the Institution and Council at which he is present, and shall regulate and keep order in the proceedings. The President shall hold office for one year only, but shall be eligible for re-election at the expiry of the year.

Who may be Vice-Presidents.

19. Members only shall be eligible for election as Vice-Presidents. In the absence of the President, the Vice-Presidents in rotation shall preside at meetings of the Council and Institution. The Vice-Presidents shall hold office for three years.

Chairman to have casting vote.

20. In case of the absence of the President and all the Vice-Presidents, the meeting may elect any one of the Council, or any Member, to preside. In all cases the Chairman of any meeting shall have a Deliberative Vote and a Casting Vote.

Who may be Councillors.

21. Members and Associates only shall be eligible for election as Ordinary Members of Council, and shall hold office for three years, and not more than three Associates shall hold office in the Council at any one time.

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22. Past Presidents of the Institution shall be *ex officio* Honorary Members of Council.

First Council.

23. The Office-Bearers in office at 30th April, 1902, shall continue in office till the first General Meeting of the Institution in October, 1902, when a new Council shall be elected in terms of these articles. Such Office-Bearers shall be eligible for election for the new Council. Of the new Council, two Vice-Presidents shall retire in October of each of the years 1903, 1904, and 1905, their places being filled by election, and the persons elected shall hold office until the expiry of the terms of office. Similarly of the new Council, six Councillors (being five Members and one Associate) shall retire in October, 1903, and a like number in October, 1904, and the remainder in October, 1905, their places being filled by election at these dates respectively, and their successors retiring at the expiry of the terms of office, and so on thereafter, from year to year. The Vice-Presidents to retire in October, 1903 and 1904, shall be determined by lot among the six Vice-Presidents first elected, and the Members of Council to retire in October, 1903 and 1904, shall be determined by lot among the Members of Council first elected. The Vice-Presidents and the Ordinary Members of Council who fall to retire at the dates mentioned, or who fall to retire at any time on the expiry of their term of office, shall not be eligible for re-election in the same capacity, nor shall a retiring Vice-President be eligible for election as a Member of Council until one year has elapsed from the date of retiral.

Retiral of Members of Council.

Office-Bearers to be elected by Ballot.

24. The Members of Council shall be elected by ballot at the Annual General Meeting, such meeting being the last Ordinary Meeting held in each month of April, but the new Office-Bearers elected at this meeting shall not enter office until 1st October following. In the election of President, Vice-Presidents, and Ordinary Members of Council from the

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Class of Associates, all Members, Associate Members, and Associates shall be entitled to vote. In the election of the other Members of Council only Members and Associate Members shall be entitled to vote.

Lists for Election.

25. In March of each year the Council shall meet and prepare a list of names for the election of Council for the ensuing year. This list shall be submitted to the Members at the Monthly Meeting preceding the Annual Meeting, and the Members present may, by motion, duly seconded, propose any additional names for any of the offices.

Ballot Lists to be sent to Members.

26. Fourteen days before the General Meeting in April of each year the list as proposed by the Council for the election of Members and others to fill the vacancies in the Council for the ensuing year, with such additions as may have been made thereto under Article 25, shall be printed and sent to all Members and Associate Members, and the list shall serve as a ballot paper. A similar list shall be printed and sent to all Associates containing the names of those for whom they are entitled to vote. Those persons entitled to vote may vote for as many names on the list as there are vacancies to be filled. In the event of any ballot paper not containing names equal to the number of vacancies to be filled, such ballot paper shall be treated as a spoiled paper.

The ballot papers may be sent by post or otherwise to the Secretary, so as to reach him before the day and hour named for the Annual General Meeting, or they may be presented personally by those entitled to vote, at the opening of the meeting.

Vacancies occurring during the Session to be filled up by the Council.

27. A vacancy occurring during any Session in consequence of the resignation or death of any Office-bearer (except the President) shall be filled up by the Council, until the next Annual General Meeting for electing Office-Bearers. Any vacancy in the office of President shall be filled up at the next General Meeting of the Institution. A person

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elected to fill a vacancy shall hold office for the period unexpired of the term of office of the Office-Bearer resigning or dying or being removed from office, and he shall not be eligible for re-election.

SECTION IV.—POWERS AND DUTIES OF COUNCIL.

Meetings of Council.

28. The Council shall meet as often as the business of the Institution requires, and during each Session—that is, from October till April—the Council shall meet at least once a month.

Committees.

29. The Council may delegate any of their powers to Committees consisting of such Members of the Council as they think fit, and they may appoint Committees to report to them upon special subjects. In particular, they shall appoint a Finance Committee to superintend the finances of the Institution, a Library Committee to superintend Library arrangements, and a Papers Committee to arrange for papers being submitted at meetings of the Institution. The Minutes of all Committees shall not take effect until approved of by the Council. The President shall be *ex officio* a Member of all Committees.

Honorary Treasurer.

The Convener of the Finance Committee shall be styled Honorary Treasurer. He shall be elected by the Council from their number, and notwithstanding the provision for retiral in Article 23, he shall be entitled to retain the office of Honorary Treasurer for three years from the date of his appointment.

Bye-laws, etc.

30. The Council may make Bye-Laws and Regulations for carrying on the business of the Institution, and, from time to time, alter, amend, repeal, vary, or add to the same; but any Bye-Law or Regulation, or any alteration or amendment thereon, or addition thereto, shall only come into force after the same has been confirmed at a General Meeting of the Institution, and no Bye-Law or Regulation shall be made under the foregoing which would amount to

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such an addition to or alteration of these Articles as would only be legally made by a Special Resolution passed and confirmed in accordance with Sections 50 and 51 of the Companies Act, 1862. The Council shall be entitled to invest the Funds of the Institution as they think fit, on such security, heritable or moveable, as to them shall seem proper, and may alter or vary the investments from time to time. The Council may purchase or sell property, heritable or moveable, for the use of the Institution, and may borrow money on the security of the property of the Institution, subject to confirmation by the Institution at an Extraordinary Meeting called for the purpose.

Investments.

Council may purchase or sell.

Borrowing.

31. The Council shall appoint a Secretary and a Treasurer, and any other official or servant required to carry on the work of the Institution, and the appointments made by the Council shall be on such terms and conditions as the Council may think fit.

Officials appointed.

32. All questions in or before the Council shall be decided by vote, and such vote shall be taken by a show of hands or by ballot; but at the desire of any four Members present the determination of any subject shall be postponed till the next meeting of Council.

Votes at Council Meetings.

Section V.—SECRETARY AND TREASURER.

33. Subject to Regulations by the Council, the Secretary (who may also act as Treasurer) shall conduct the correspondence of the Institution; attend all meetings of the Institution, of the Council, and of Committees; take Minutes of the proceedings of such meetings, and enter them in the proper books provided for the purpose; read at all meetings of the Institution and Council respectively the Minute of the preceding meeting, and all communications received by him or ordered to be read; superintend the publication of such papers as the Council may direct; take charge of the Library; issue notices of meetings; issue diplomas; keep the Roll and Regis-

Duties of Secretary.

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ters; and perform whatever other duties are indicated in the Regulations of the Institution as appertaining to his department or set forth in the terms of his appointment.

Duties of Treasurer.

34. Subject to regulation by the Council, the duties of the Treasurer shall be to take charge of the property of the Institution (excepting books, papers, drawings, models, and specimens of materials, which shall be in charge of the Secretary); to receive all payments and subscriptions due to the Institution; to direct the collection of subscriptions; to pay into one of the Glasgow Banks, in the joint names of the President, Honorary Treasurer, and himself, the cash in his hands whenever it shall amount to Ten Pounds; to pay all sums due by the Institution, but not without an order signed by two Members of the Finance Committee, and to keep an account of all his intromissions in the General Cash Book of the Institution, which shall upon all occasions be open to inspection of the Finance Committee, and which shall be balanced annually, as at 30th September. The Treasurer shall prepare an Annual Statement of the Funds of the Institution, and of the receipts and payments of each financial year, which shall be audited by the Auditor aftermentioned, and this Statement of the Funds and an Inventory of all the property possessed by the Institution, and a List of the Members, Associate Members, Associates, and Students whose subscriptions are in arrear, shall be submitted to the First Meeting of the Council, in October.

Annual Report.

35. An Annual Report upon the affairs of the Institution shall be drawn up under the direction of the Council at a meeting to be held not less than ten days before the General Meeting of the Institution in October. This report shall embody reports from the representatives elected by the Council to various official bodies.

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Section VI.—AUDIT OF ACCOUNTS.

Auditor and duties.

36. An Auditor, who must be a Chartered Accountant of at least five years standing, shall be appointed by the Council at their meeting preceding the last General Meeting of each Session, to examine the accounts and books of the Treasurer, and the Annual Financial Statement or Statements of the Funds, and that Statement, along with the Audit and Annual Report, shall be printed in the notice calling the First General Meeting of the Institution in October, and shall be read at that meeting.

Section VII.—MEETINGS AND PROCEEDINGS OF THE INSTITUTION.

Ordinary General Meetings every four weeks during the Session.

37. The Institution shall hold ordinary meetings for reading papers, and for discussing matters connected with the objects of the Institution; and such meetings shall take place regularly, at least once in every four weeks during each Session; and may be adjourned from time to time. The Sessions shall commence in October, and continue until the month of April next following, inclusive. No business shall be transacted at any meeting unless 25 Members shall be present.

At the General Meeting in April of each year for the election of Office-Bearers, the order of business shall be:—

(1) Minutes of last meeting.
(2) To read and consider the reports of the Council and Treasurer.
(3) The meeting shall nominate two Scrutineers, who shall be Members, and shall hand to them the ballot-box containing the voting papers for the new Office-Bearers.
(4) The Scrutineers shall receive all ballot papers which may have reached the Secretary, and all others which may be pre-

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sented at the meeting. The Scrutineers shall then retire and verify the lists and count the votes, and shall, before the close of the meeting, report to the Chairman the names which have obtained the greatest number of votes subject to the conditions of the ballot. The Chairman shall then read the list presented by the Scrutineers, and shall declare the gentlemen named in the list to be duly elected, provided always that the list does not contain more names than there are vacancies to be filled.

Ordinary Meetings—order of business.

38. At every ordinary meeting of the Institution, the Secretary shall first read the Minutes of the preceding meeting, which, on approval, shall then be signed by the Chairman of the meeting at which the Minutes are read and approved. The Secretary shall next read any notices which may have to be brought before the meeting; after which any Candidates for admission may, if necessary, be balloted for, and any new Members shall be admitted. Any business of the Institution shall then be disposed of, after which notices of motion may be given. The paper or papers for the evening shall then be read and discussed. Each Member shall have the privilege of introducing one friend to the General Meetings, whose name must be written in the Visitors' Book, together with that of the Member introducing him; but if the introducing Member be unable to attend the meeting, he may send with the visitor a card signed by him addressed to the Secretary. During such portions of any of these meetings as may be devoted to any business connected with the management of the Institution, visitors may be requested by the Chairman to withdraw.

Nature of papers to be read.

39. All papers read at the meetings of the Institution must be connected with the Science or Prac-

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tice of Engineering or Shipbuilding, and must be accepted by the Papers Committee before being read.

Proceedings to be published.

40. The papers read, and the discussions held during each Session, or such portion of them as the Council shall select, shall be printed and published forthwith.

Explanatory notes after reading of papers may be published.

41. Explanatory notes communicated after the reading or discussing of papers may be printed in the *Transactions*, if the Council see fit.

Copyright of papers shall be the property of the Institution.

42. The copyright of any paper read at a meeting of the Institution with its illustrations, shall be the exclusive property of the Institution, unless the publication thereof by the Institution is delayed beyond the commencement of the Session immediately following that during which it is read; in which case the copyright shall revert to the author of the paper. The Council shall have power, however, to make any arrangement they think proper with an author on first accepting his paper.

Members, etc. to receive copies of *Transactions*—Authors 30 copies of their papers.

43. The printed *Transactions* of each Session of the Institution shall be distributed gratuitously, as soon as ready, to those who shall have been Members, Associate Members, Associates, or Honorary Members of the Institution during such Session, and they shall be sold to the public at such prices as the Council shall fix. Authors of papers shall be entitled to thirty separate copies of their papers, with the discussions, as printed in the *Transactions*.

Special Meetings may be called by the Council or on requisition by 25 Members.

44. Extraordinary or Special Meetings may be called by the Council when they consider it proper or necessary, and must be called by them on receipt of a requisition from any 25 Members, specifying the business to be brought before such meeting.

Voting.

45. Any question which, in the opinion of the President or the Chairman of the meeting of Council and Institution, is of a personal nature shall be decided by ballot; all other questions shall be decided by a show of hands, or by any convenient system of

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Who may vote.

open voting. In all cases, not hereinbefore provided for, only Members, Associate Members, and Associates shall be entitled to vote. Every Member, Associate Member, and Associate shall have one vote only, which must be given personally.

Section VIII.—SUBSCRIPTIONS OF MEMBERS AND OTHERS.

Annual Subscription payable.

46. Each Member shall, on election, pay an Entrance Fee of £1, and for the current and for each Session thereafter an Annual Subscription of £3.

Each Associate Member shall, on election, pay an Entrance Fee of £1, and for the current Session and each of the two following Sessions an Annual Subscription of £1 10s., and thereafter an Annual Subscription of £2 5s.

Each Associate shall, on election, pay an Entrance Fee of £1, and for the current Session and each Session thereafter an Annual Subscription of £2 5s.

Each Student shall pay an Annual Subscription of Fifteen Shillings, but no Entrance Fee.

In the case of Members, Associate Members, Associates, and Students, elected during March and April, no subscription shall be payable for the current Session.

47. Honorary Members shall be liable for no contribution or subscription or Entrance Fee.

48. The liability of any Member or Associate for future Annual Subscriptions may be commuted by the following payments—viz., in the case of a Member, by the payment of £40; and in the case of an Associate by the payment of £30, and, in the event of such payment being made by a Member or Associate on his admission to the Institution, the same shall be in full of Entry Money as well as future Annual Subscriptions.

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49. All persons transferred, in terms of Articles 10 and 11, to the Roll of Members, Associates, or Students, to be kept under these Articles, shall not be liable to pay any Entrance Fee, but for the Session 1902-3, and thereafter, they shall be liable for the Annual Subscription applicable to the Class to which they are transferred. All persons who, as Members or Associates under the former Articles of Association, had commuted their Annual Subscriptions by a capital payment to the Institution shall not be liable for any subscription, notwithstanding the terms of this Article.

When Annual Subscriptions due.

50. Annual Subscriptions shall become due on the first day of October in each year, and must be paid before 1st January following.

Members, etc., not entitled to vote if in arrear.

51. No Member or Associate Member or Associate whose subscription is in arrear shall be entitled to vote at any meeting of the Institution nor to receive copies of papers or proceedings while the subscription remains unpaid.

52. Any Member, Associate Member, Associate, or Student whose subscription is more than three months in arrear shall be notified by the Secretary. Should his subscription become six months in arrear he shall be again notified by the Secretary, and all his rights in connection with the Institution shall be suspended. Should his subscription become one year in arrear he shall be removed from the Roll of the Institution unless the Council may deem it expedient to extend the time for payment.

Members, etc., retiring from the Institution.

53. Any Member, Associate Member, Associate, or Student retiring from the Institution shall continue to be liable for Annual Subscriptions until he shall have given formal notice of his retirement to the Secretary. Contributions payable by Members, Associate Members, Associates, or Students shall

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be debts due to the Institution, and may be recovered by the Treasurer.

Remission of subscription in certain cases.

54. In the case of any Member or Associate who has been long distinguished in his professional career, but who, from ill health, advanced age, or other sufficient cause, does not continue to carry on a lucrative practice, the Council, if they think fit, may remit the Annual Subscription of such Member or Associate, and they may remit any arrears due by him. Any such case must be considered and reported upon to the Council by a Committee appointed by the Council for the purpose.

Council may refuse to receive subscriptions in certain cases.

55. The Council may refuse to continue to receive the subscription of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall, in the opinion of the Council, have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution, and may remove his name from the Register, and he shall thereupon cease to be a Member, Associate Member, Associate, or Student (as the case may be) of the Institution.

Section IX.—GENERAL POWERS AND PROVISIONS.

Powers of Institution in General Meeting.

56. Any Extraordinary or Special Meeting of the Institution, duly called, shall have power by a majority in number of the persons present thereat entitled to vote, from time to time, to review the decisions or determinations of the Council; to remove Members of Council; to expel Members, Associate Members, Associates, Students, or Honorary Members from the Institution, and to expunge their names from the Roll; and to delegate to the Council all such further powers as may be considered necessary for efficiently performing the

To delegate powers to Council.

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business of the Institution. At any Extraordinary or Special Meeting 50 Members shall be a quorum.

57. The Institution shall have a common seal, which will be under the charge of such of the Office-Bearers as the Council may appoint, and all instruments bearing the seal shall be countersigned as the Council shall direct. Common Seal.

Section X.—NOTICES.

58. Notices requiring to be served by the Institution upon its Members, Associate Members, Associates, Students, or Honorary Life Members may be served either personally, or by leaving the same, or by sending them through the post; and notices so posted shall be deemed to have been duly served. No Members, Associate Members, Associates, Students, or Honorary Life Members who have not a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to any such. Notices.

59. Notices for any General or Extraordinary or Special Meeting of the Institution may be given by the Secretary to all Members, Associate Members, Associates, or Honorary Life Members at least four days before such meeting. Notices of any adjourned meeting shall be given at least two days before the adjourned meeting is held. Such notices shall specify the nature of the business to be transacted, and no other business shall be transacted at that meeting. Induciæ of Notices.

60. Notices for any meeting of Council must be given by the Secretary at least four days before such meeting. Notices for the meeting of Committees shall be given as the Council shall direct. Notices.

61. In computing the *induciæ* of any notice, the day on which the same is delivered shall be reckoned as an entire day. Computation of Induciæ.

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APPENDIX.

FORM *A*.

Form of Recommendation and Undertaking.

A. B.....of.....being upwards of.....years of age, and being desirous of belonging to the Institution of Engineers and Shipbuilders in Scotland, I recommend him, from personal knowledge, as in every respect worthy of that distinction because (here specify distinctly the qualifications of the Candidate according to the spirit of Articles 5, 6, 7, and 8).

On the above grounds I beg leave to propose him to the Council as a proper person to belong to the Institution.

.....*Member.*

Dated this.....*day of*.....19

We, the undersigned, from personal knowledge, concur in the above recommendation.

.....*Member.*

.....*Member.*

I, the said A. B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

.....

The Council having considered the above recommendation present A. B. to be balloted for as.....of the Institution of Engineers and Shipbuilders in Scotland.

Passed by the Council.....19

Balloted for.....19

.....*President (or Chairman).*

FORM *B*.

Form for Transfer from one Class to another.

A. B.....of.....having been a.....of the Institution of Engineers and Shipbuilders in Scotland for.....years, and being desirous of becoming a.....of the Institution, we, from personal knowledge, recommend him as in every respect worthy of being elected a.....of the Institution.

.....*Member.*

.....*Member.*

.....*Member.*

I, the said A. B., do hereby promise that in the event of my election I will abide by the Rules and Regulations of the Institution, and that I will promote the objects of the Institution as far as may be in my power.

.....

The Council having considered the above recommendation and undertaking approve of the same.

.....*President (or Chairman).*

Dated this.....*day of*.....19

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BYE-LAWS.

MEDALS AND PREMIUMS.

Marine and Railway Engineering Medals.

1. Each of the two Medals founded by subscription, for the best paper in the Marine and Railway Engineering Departments respectively, shall be awarded by the vote of a General Meeting, not oftener than once in each Session.

Institution Medal.

2. The Council shall have power to offer annually a Medal for the best paper on any subject not comprehended by the Marine and Railway Engineering Medals. Such additional Medal to be called the Institution Medal, and to be paid for out of the funds of the Institution, until a Special Fund be obtained. This Medal also shall be awarded by the vote of a General Meeting.

When Medals may not be awarded.

3. If it shall be the opinion of the Council that a paper of sufficient merit has not been read in a particular department during any Session, the Medal shall not be given in that department; and, in the case of the Marine and Railway Engineering Medals, the interest arising from the particular Fund shall be added to the principal.

Medals and Books may be awarded.

4. If the person to whom a Medal may be awarded shall express a wish to receive a Bronze Medal, accompanied with the extra value in books, in lieu of the ordinary Gold Medal, the award shall be made in that form. The Council may recommend premiums of books in lieu of, or in addition to, the Gold Medals. The value of such premiums of books to be determined by the Council.

MANAGEMENT OF THE LIBRARY.

Appointment of Library Committee.

5. The Council, at their first meeting each Session, shall appoint eight of their number to form a Library Committee, one of the eight to be Honorary

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Librarian and Convener of the Committee. Three Members of the Committee shall form a quorum.

Secretary shall have charge of Library.

6. The Secretary of the Institution shall have charge of the Library, and shall also act as Secretary of the Library Committee.

Powers of Library Committee.

7. The Library Committee, subject to the sanction of the Council, shall expend in books and Library expenses the sums placed at their disposal, and, subject to the approval of the Council, may make Bye-Laws for the management of the Library, and appoint assistants. The sum of £30 or thereby shall be expended annually out of the funds of the Institution, in the purchase of books for the Library, in addition to the ordinary expenditure in binding, etc.

Duties of Library Committee and Annual Report.

8. The Library Committee shall annually make an examination of the property in connection with the Library, and report to the Council, detailing the state of the Library affairs.

LIBRARY BYE-LAWS AS TO USE OF BOOKS.

When Library is to be open.

9. Except during Holidays and Saturdays, the Library shall be open each lawful day from 1st May till 30th September inclusive, from 9.30 a.m. till 5 p.m. On Saturdays the Library shall be open from 9.30 a.m. till 1 p.m. On the 1st October and thereafter throughout the Winter Session the Library shall be open each lawful day from 9.30 a.m. till 8 p.m., except on meeting nights of the Institution and Royal Philosophical Society, when it shall be closed at 10 p.m. The Library shall be closed for the Summer Holidays, from the 11th July till 31st July inclusive.

Who may borrow books.

10. Books shall not be lent to any persons except Members, Associate Members, Associates, Students, or Honorary Members of the Institution; but a person entitled to borrow books may send a messenger with a signed order.

11. The books marked with an asterisk in the

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Catalogue shall be kept for consultation in the Library only, and shall not be lent. Books for consultation only.

12. The Librarian and Assistant Librarian shall take their instructions from the Secretary of the Institution. They shall keep an Accession Book, in which shall be entered the particulars of all books purchased for or donated to the Library. Librarian to keep Accession Book.

13. The Librarian, or Assistant Librarian, shall keep a Register in which he shall enter the titles of the book or books lent, the date of lending, the name of the borrower, and the date of the return of the book or books to the Library. Register kept of books lent.

14. The borrower of the book or books, or, in his absence, the bearer of his order, shall sign his name to the entry of such borrowing in the Librarian's Register. Borrower to sign for books.

15. The Librarian, or Assistant Librarian, shall sign his initials to the date of the return of the book or books. Librarian to certify return of books.

16. The borrower shall be responsible for the safe return of the book, and if it be damaged or lost he shall make good such damage or loss. Should books be returned in a damaged condition, the Librarian, or Assistant Librarian, shall immediately make an entry of the fact in the Register, and report the same to the Library Committee without delay; and he shall give notice in writing of such entry, and report to the person from whom he last received the book, within three clear days of the receipt of the book, exclusive of the day of receiving the book and the day of giving such notice. Books damaged to be entered in Register. Intimation to Library Committee, and notice to last borrower.

17. No person shall be entitled to borrow, or have in his possession at one time, more than two complete works belonging to the Library, or two volumes of any periodical. Number of books which may be borrowed at one time.

18. No person being six months in arrears with his subscription to the Institution shall be at Liberty to use the Library or Reading Room. Persons in arrears of subscription not to have use of Library.

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Time books may be obtained.

19. No borrower shall have the right to retain a book longer than thirteen clear days, exclusive of the days of borrowing and returning; and written notice shall be sent to the borrower one day after the time has expired. In no case shall any book be kept longer than twenty clear days.

Lots to be drawn when two may apply for the same book.

20. In the event of two or more persons applying for the same book at the same time, the applicants shall draw lots for priority.

Introduction of friends to Reading Room.

21. Each Member shall be entitled to introduce a friend to the Reading Room, whose name shall be written in the Visitors' Book, together with that of the Member introducing him.

Annual scrutiny of books.

22. All books belonging to the Library shall be called in for inspection, and the lending out of books shall be suspended in each year for one week, being the last seven clear days of March; and all Members shall be required, by an intimation to be inserted in the notice calling the preceding meeting of the Institution, to return all books in their hands to the Library on or before the day next preceding the period before mentioned.

NOTE.—The Library and Reading Room are open to Members, Associate Members, Associates, and Students; and the Library of the Philosophical Society is open for consultation.

WILLIAM BROWN, *Convener.*
WILLIAM M. ALSTON.
PROF. A. BARR, D.Sc.
W. A. CHAMEN.
E. HALL-BROWN.
WILLIAM MELVILLE.
JOHN STEVEN.
JOHN WARD.
EDWARD H. PARKER, *Secretary.*

21*st April*, 1903.

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INSTITUTION
OF
ENGINEERS AND SHIPBUILDERS
IN SCOTLAND
(INCORPORATED).

PRESIDENTIAL ADDRESS

By R. D. MOORE, B.Sc.,
President of the Institution.

4th October, 1927.

In accordance with the time-honoured custom, my first duty to-night is to tender my most cordial thanks to you for the great honour you have done me in electing me your President. I look back over the names of my predecessors in office, all outstanding members of the engineering or shipbuilding professions in their day, and find that I am the first professional metallurgist to be called to occupy the Presidential chair. This qualification, I fear, does not in any way increase my fitness for the position. I have, however, had a long association with the Institution, and as a Member of Council in various capacities, extending over 13 years, I have endeavoured during that period to work whole-heartedly in the interests of the Institution. You can rely upon my continuing to further these interests to the best of my ability.

A president, in the choice of the subject of his address, is allowed much latitude, and he usually selects the one on which his business association entitles him to speak with some

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authority. In my case that is steel, and I have the satisfaction of knowing that the subject is one which appeals in no small degree to members of this Institution, as the material predominates so largely in the work of the shipbuilder and engineer. Indeed, it might even be said that steel occupies first place in the prosperity of an industrial nation. Britain realises this now, when she has ceased to be the unchallenged chief steel producer for the world. Fifty years ago she supplied the ships, engines, and engineering material for almost the whole of the world, without serious competition, because she was favoured among nations in having within her borders the only convenient ores from which pig iron, suitable for making good steel, could then be produced.

America was the first serious rival, and, developing her vast resources of material, soon outstripped this country in output, though it is only within comparatively recent times that she has been able to put her steel upon European markets. Germany, requiring to import high-grade pig iron, lagged far behind, until in 1877 two Welsh chemists, Sydney Thomas and Percy Gilchrist, discovered and introduced the basic process of steel making. This put Germany in the position, by employing her Lorraine ores, which were pre-eminently suitable for the basic process, of turning out cheaply the best qualities of mild steel. It was in 1879 that the basic process was first worked on a commercial scale at Middlesborough, and Germany forthwith adopted it. From this period Germany advanced by leaps and bounds as an industrial nation, and it may almost be said that she owes her great all-round industrial development, during the 30 years before the war, to the opportunity given her by two Welshmen of becoming a great steel-producing country.

Fig. 1 shows the steel outputs of Britain, America, and Germany commencing at 1877, which marks the beginning of the struggle of these nations for first place in output, till 1921, the slump period after the war. It will be seen from this diagram that the United States and Britain first coincided in output at 1879, and it was 1893 before Germany outstripped

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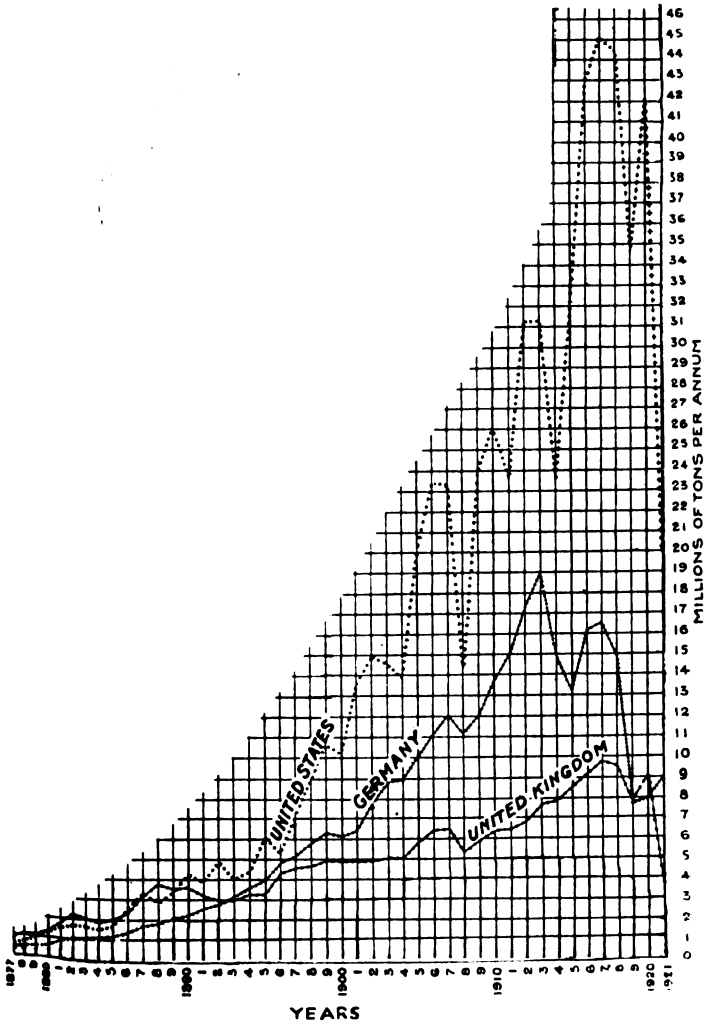

Fig. 1.

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Britain in output. But Germany, excepting during 1919 to 1921, and the United States, continued to keep well ahead. The largest outputs of the three countries are:—

	Output.	Year.
United States - - -	47,134,000	1926
United Kingdom - -	9,553,715	1917
Germany - - -	18,935,089	1913

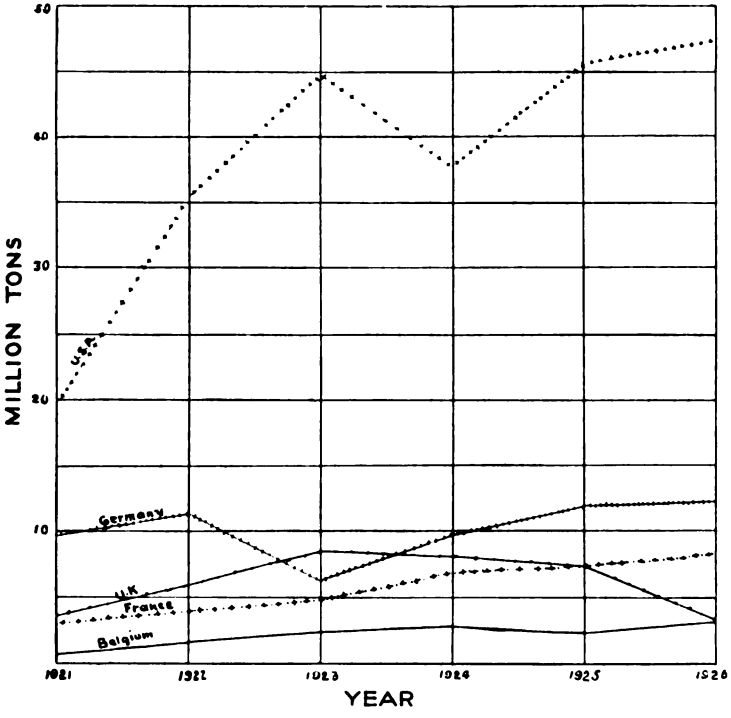

Fig. 2.—Yearly Steel Output.

In 1926 the world's steel-making capacity was estimated roughly to be 116,000,000 tons. Of this, one-half has to be credited to the United States, which could produce four times as much as Britain and three times as much as Germany. Fig. 2 shows the yearly output of steel from 1921 to 1926. The

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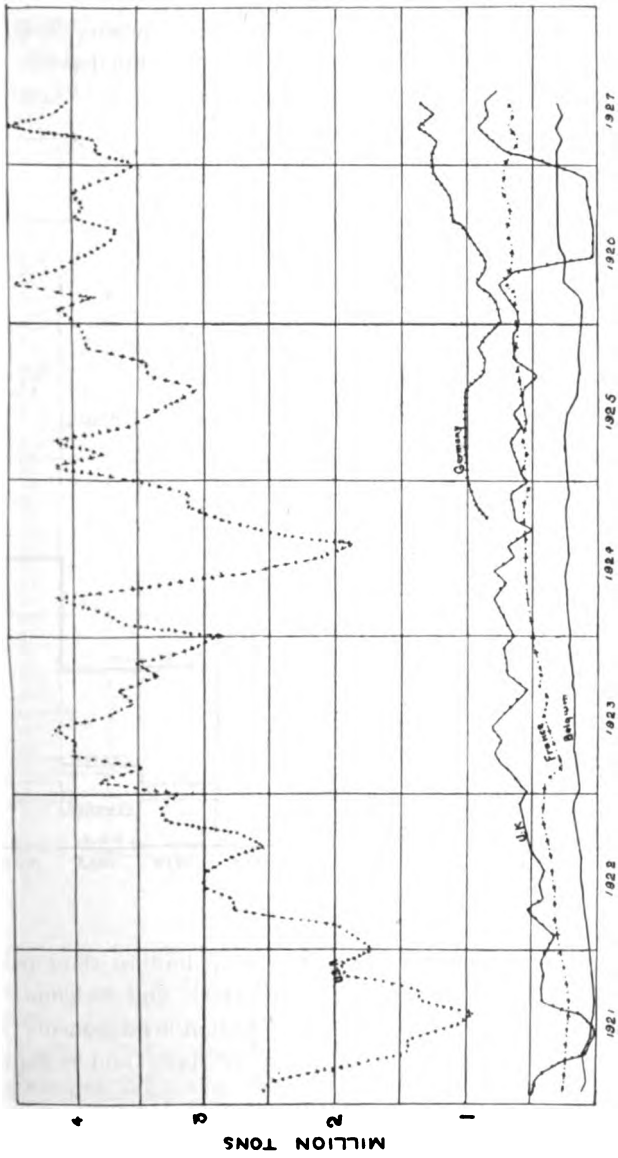

Fig. 3.

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figures of this period may be taken as indicating the capacity of recovery of the nations after the slump resulting from the war. I have included France, as, having regained possession of the Lorraine ore deposits under the Treaty of Versailles,

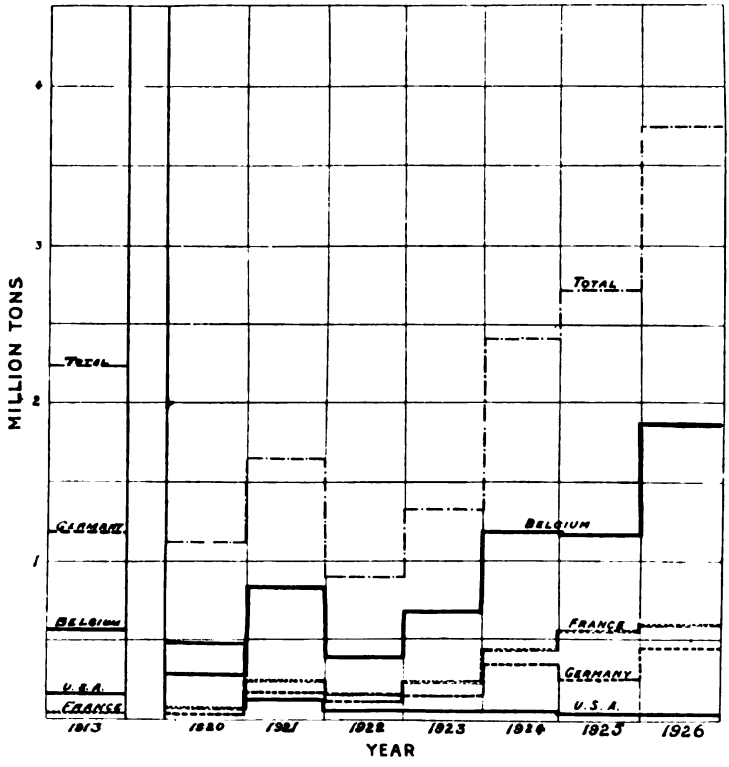

Fig. 4.

she bids fair to outrival the United Kingdom in third place, with an output of 8¼ million tons in 1926; and Belgium, as, with the special advantages under reparation arrangements, she has been able to bring her plant up to date, and is rapidly increasing her output.

Fig. 3 illustrates the output by months, and shows the steady increase of France and Belgium more strikingly. In

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the case of Germany, no reliable details are available from 1919 till the end of 1924. In 1923 the occupation of the Ruhr by the French completely suspended iron and steel making in that part of Germany during the year, but the rapid recovery

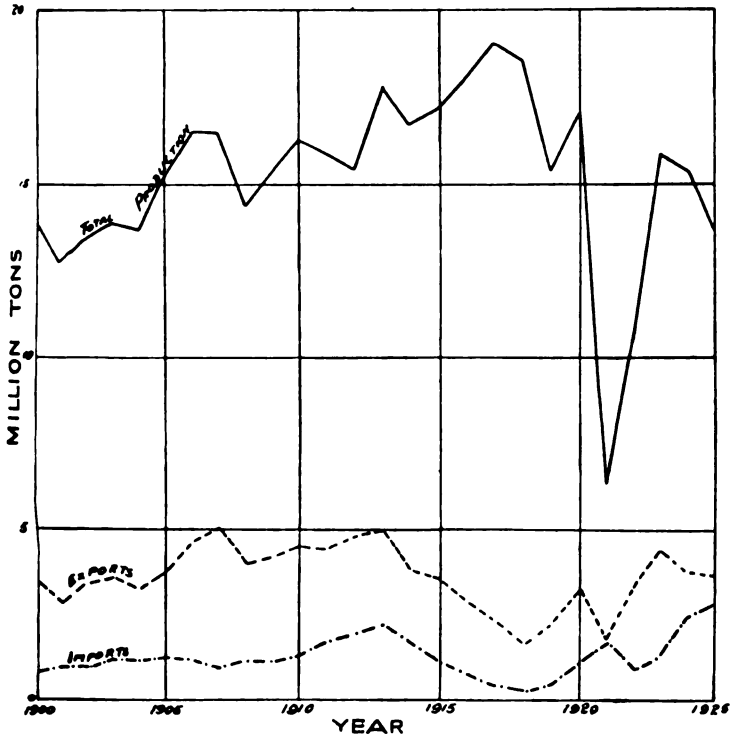

Fig. 5.

after that date is remarkable. The curve for the United States shows many ups and downs, but as these are all well above the line of depression, they indicate varying degrees of prosperity only. That for the United Kingdom shows deep depressions at 1921 and 1926, the years of coal strikes, and generally no decided upward tendency. The start after the end of the coal strike in 1926 gave prospect of a revival of trade

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in Britain. Indeed, had the output of March been continued on the same scale, a yearly output of over 11 million tons

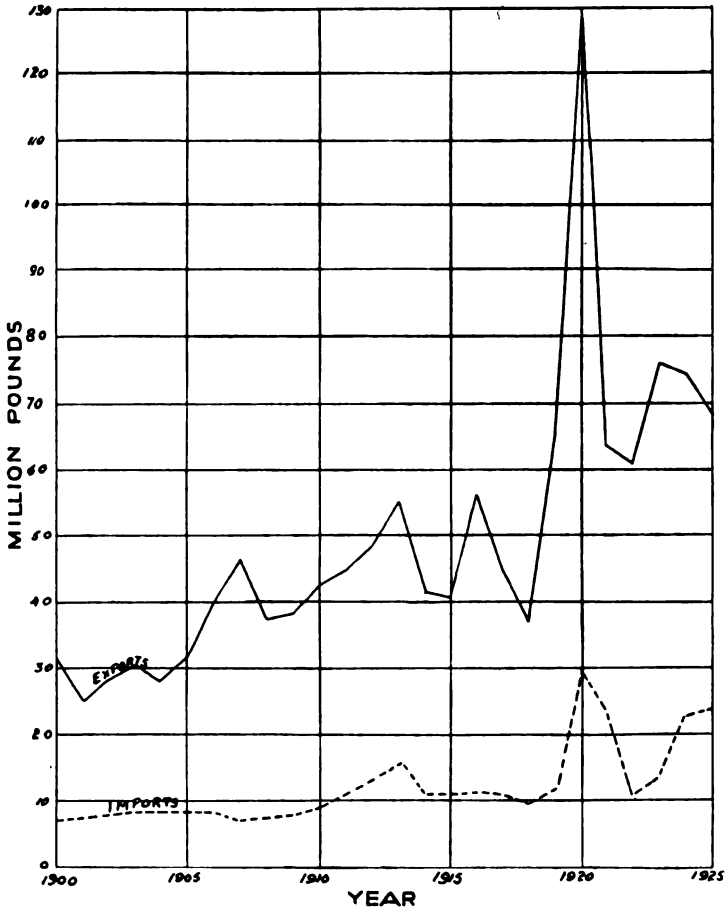

Fig. 6.

would have been attained. However, this did not prove to be the trade wind hoped for, but only a passing breeze, and the British steel industry is not yet out of the doldrums.

Fig. 4 gives the imports of iron (including pig iron) and

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steel into the United Kingdom from Germany, Belgium, France, and the United States; and these show an all-round increase from 1923, except from the United States. Compared with 1913, the noticeable feature is the decline from Germany and the increase from Belgium. Indeed, in 1926 Belgium appears to have supplied over 50 per cent. of the total. Possibly, however, this figure includes French and German material shipped at Antwerp, and not specially entered. A steadily-increasing figure is shown from France. The United States, being concerned in an increasing demand for her internal use, has little to spare for export.

Fig. 5 shows the total British iron and steel imports and exports, and the total production from 1900 to 1925. I have not included 1926, because the coal strike caused this to be an abnormal year, the imports exceeding the exports for the first time; the figures are, exports 2,987,700 tons and imports 3,740,279 tons. Fig. 6 illustrates the money values of the imports and exports given in Fig. 5.

The figures in Table I are interesting, as showing an increasing export of iron and steel to British possessions:—

TABLE I.

	1913	1920	1923	1924	1925
Total Foreign countries -	2,596,826	1,840,899	2,360,484	1,923,494	1,491,510
Total British possessions	2,372,399	1,410,326	1,957,053	1,927,941	1,694,791
Unallocated -	—	—	—	—	544,722
Grand total -	4,969,225	3,251,225	4,317,537	3,851,435	3,731,023
Value, £	55,350,747	128,907,361	76,155,978	74,534,129	68,162,243

At the present time special calls are being made upon the metallurgist to produce a suitable material to meet the conditions of high-pressure and superheated steam. During the Summer Meeting many had the opportunity of studying the

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boilers of the "King George V," which is the latest outcome of the realisation that further economy in the use of steam lies along the lines of still greater pressures and temperatures. The pressure of 575 lbs. per square inch at the boilers, with a temperature of 750 degrees F. in the "King George V," has been greatly exceeded in land installations. At the Edgar Station of the Edison Electric Illuminating Co., Boston,

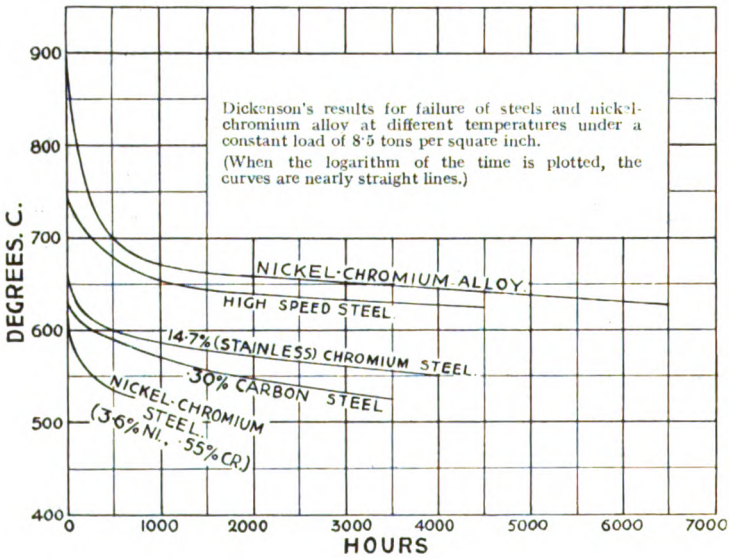

Fig. 7.

U.S.A., boilers have been working at a steam pressure of 1,200 lbs. for about two years. The boilers were forged by the Midvale Steel Co. from 78-inch ingots, trepanned and pressed. The design has just been laid down for the first extension at that station, which will consist of two 1,500 h.p. boilers for a working pressure up to 1,500 lbs., with 1,400 lbs. as the normal operating pressure. Up to this point, steel has satisfactorily withstood the conditions imposed upon it, but it is questionable if it can be relied upon to do so much higher up the scale of temperature and pressure.

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Prof. Desch, of Sheffield University, has kindly furnished me with details relative to the behaviour of steel under varying temperatures. Fig. 7, produced from the results obtained by Mr. J. W. S. Dickenson, of Messrs. Vickers, Ltd., is very interesting. He found that a nickel-chromium alloy of 70 per cent. nickel, 15·5 per cent. chromium, and 0·54 per cent. carbon, stood better than any steel. The test conditions were carried on uninterruptedly over a prolonged period, even up to three years, and this makes the results specially useful. Table II gives the results obtained by Prof. Lea, of Sheffield University, and shows the stress at different temperatures above which creep is continuous. At higher loads, therefore, failure would take place if the duration of test were sufficiently prolonged.

These experiments were not continued over such long periods as those carried out by Dickenson, so they do not give results which may be so usefully applied in the consideration of actual working conditions. The general inference to be drawn from the results of these tests is that nickel steels stand better than plain carbon steels; high chromium steels also stand high temperatures well, but those alloy steels containing a high percentage of both nickel and chromium stand best of all. Steels, however, are surpassed by nichrome alloys, in respect of their capacity to stand high temperatures, but nichrome alloys have the disadvantage that they do not forge well. In the light of these figures, it seems advisable to proceed with caution in dealing with further developments in high-pressure boilers. In the case of the "King George V," the steel of the boilers is daily subjected to conditions of excessive temperature and pressure, which are released when the vessel is tied up for the night. How will the material stand such fatigue over a period of two or three years? Under these special conditions, it is incumbent upon the metallurgist to keep a careful watch over possible deterioration of steel, and to provide the most suitable material. At present the tendency is to recommend alloys, especially chrome steel, which has

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the advantage of not scaling at any of the high temperatures likely to be employed; but it must not be forgotten that these special alloy steels depend largely for ductility upon heat treatment, and a certain advantage of this may be lost under the high temperatures of working conditions.

TABLE II.

	Temperature. Degrees C.	Stress. Tons per square inch.
Mild Steel—0·14 per cent. Carbon	230	33
	350	28
	400	14
	500	4
	600	1
Steel—0·32 per cent. Carbon	350	34
	400	18
	500	6
	600	2
Steel—0·45 per cent. Carbon	400	30
	500	9
	600	3
	700	1
Steel—0·75 per cent. Carbon	400	30
	500	16
	600	6
	700	2
Alloy Steels— 25 per cent. Nickel and high Chromium	500	18-20
	600	16
	700	9-11
	800	6

In the course of further remarks, I propose to refer briefly to the special branch of steel manufacture, namely, steel castings, in which I have been engaged for over 35 years. The beginning of steel foundry work is rather obscure, but credit for melting blister steel bars in a crucible and casting into moulds is given to Huntsman, a Sheffield watchmaker, in 1740, and up to a little over 50 years ago this was still the method of making cast steel. Germany made striking advances in this industry, and at the exhibition in London, in 1851, a crucible

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ingot weighing about 2¼ tons, the largest that had up to that time been produced, was shown by Krupp, of Essen. In the following exhibition of 1873, the same firm exhibited another ingot of 51 tons in weight. This feat was accomplished by men trained to work together with military precision, carrying crucible pots containing about ½ cwt. of melted metal, which were emptied in rapid succession into the ingot mould. From the steel in ingots such as these, the early Krupp guns were forged. Krupp's record for crucible steel castings commences in January, 1812, and the material possessed excellent wearing qualities. Over 30 years ago I was shown a crucible steel pinion at Summerlee, Mossend, supplied by Krupp, which had been in use for a long period, and showed little signs of wear. Krupp's installed the Siemens process at their works in 1869. In this country, Sheffield claims to have a firm still operating which made crucible steel castings nearly 100 years ago. The difficulties in making large crucible steel castings gave a limited scope to this industry, and it was not till the products of the Bessemer and Siemens processes came into use, about 1870, for large castings that rapid development took place.

I am indebted to the Secretary of the Admiralty for the following details:—In 1883 a committee was appointed by the Admiralty to consider the use of steel castings in lieu of iron forgings, and as a result of their findings, larger steel castings came into use in British naval construction. The first British warships to be fitted with such castings were:—

Ship.	Commenced Building.	Completed.	Casting.
"Forth" -	Dec., 1884	July, 1889	Stem and sternpost.
"Fearless" -	Sept., 1884	July, 1887	Stem and sternpost.
"Surprise" -	Feb., 1884	Aug., 1886	Sternpost and shaft brackets.
"Alacrity" -	Feb., 1884	Aug., 1886	Sternpost and shaft brackets.
"Benbow" -	Nov., 1882	June, 1888	Shaft brackets.
"Thames" -	April, 1884	July, 1888	Shaft brackets.

The use has steadily developed until, in a modern large cruiser, the total weight of steel castings amounts to over

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700 tons, distributed between hull and machinery as detailed below:—

Hull.	Tons.	Engines.	Tons.
Propeller brackets (4)	160	Thrust blocks	40
Stem	60	Valves and branches	140
Rudder frame	50	Other castings	70
Shaft tubes	70		
Hawse pipes, bollards, fairleads, etc.	110		
	450		260

Dr. Montgomerie informs me that the date when a specification for steel castings first appeared under Lloyd's rules was

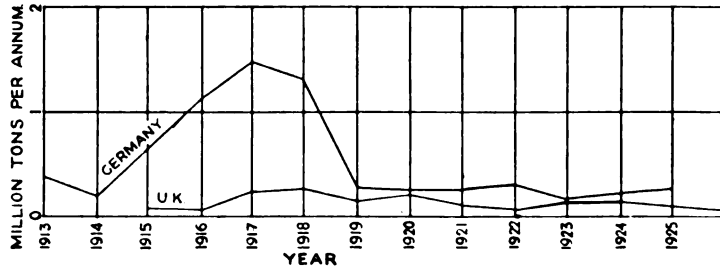

Fig. 8—Steel Castings.

1889-90, in the section appertaining to keel, stem, and sternposts. Fig. 8 shows the total yearly output of steel castings in the United Kingdom and Germany from 1913 to 1926. The large output by Germany during the war is very noticeable.

The production of crucible steel, being largely a question of the addition of the proper proportions of pig iron and scrap, melted under conditions which eliminate oxidation, offered no special difficulty in the making of sound castings. It was, however, vastly different in the case of steel castings made by the Siemens or the Bessemer process, where oxidising conditions were the essence of the process. It was found that the steel suitable for rolled material, requiring only the addition

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of manganese (Mushet's discovery), gave porous metal when used for castings. This trouble, caused by occluded gases and dissolved oxides, was overcome by the steel founder after much bitter experience, by the addition of silicon or aluminium along with the manganese. The explanation of the action of silicon and aluminium was for a long time accepted as the simple one of the reducing effect of these easily-oxidised materials upon the gases and dissolved oxides in the steel. But later, when the analysis of gases in the cold steel came to be made, this theory had to be modified. An experiment was made with two ingots of steel taken from the same heat. To one, while molten, a quantity of aluminium was added; the other had no such addition. The resulting ingots showed that the steel without aluminium was honeycombed with blowholes; the other with aluminium addition was solid. The cold steels were then analysed for oxygen, carbon monoxide, carbon dioxide, hydrogen, and nitrogen gases. The solid metal, with the addition of aluminium, gave the total volume of the gases equal to 91·86 times the volume of steel; while in the steel with blowholes and no aluminium the total volume of the gases was equal to 42·09 times the volume of steel. These results go to show that the effect of silicon and aluminium in preventing blowholes is due to the presence of these ingredients increasing the solvency of the occluded gases as well as reducing dissolved oxides.

I shall now refer to a few typical examples, and comment on some of the difficulties incidental to their manufacture. An ingot is really the simplest form of steel casting, and in cooling from the molten to the solid state passes through various stages. The molten metal, in cooling, first sets on the outsides, in a manner analogous to the freezing of water. Contraction of this set portion takes place, causing the outside to press inwards, and to relieve the strains so set up, the metal elongates. The cooling of the outside portion continues at a diminishing rate, until a point is reached when the inside layers of the set portion begin to cool more quickly than the outside. The effect of this is to cause the inside wall of set metal to

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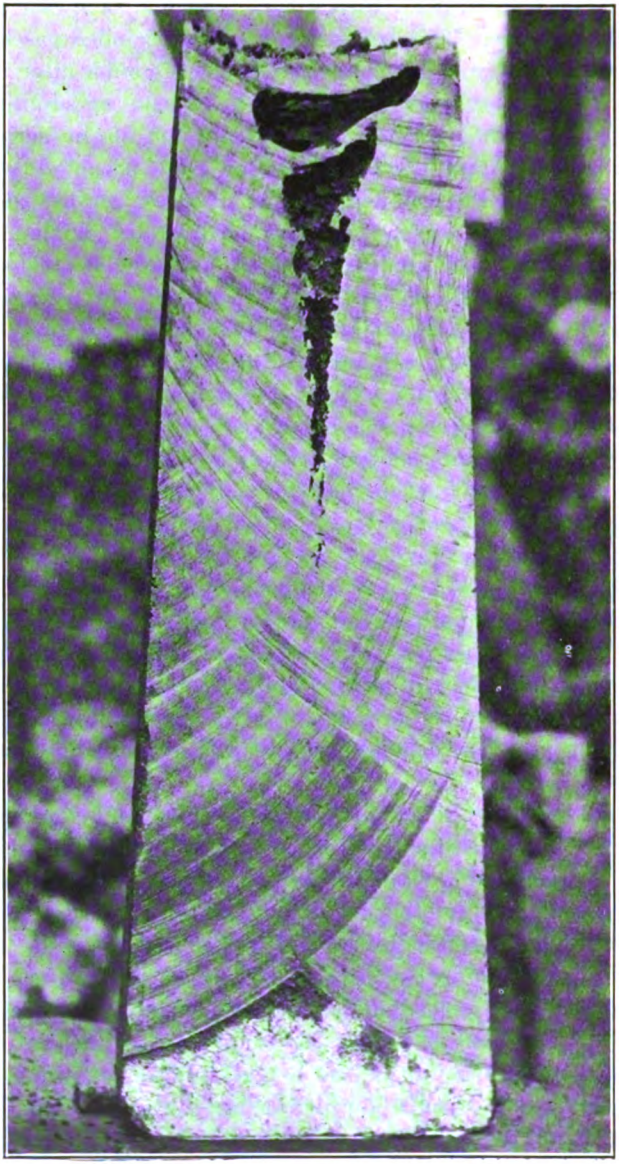

Fig. 9.

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contract towards the outside, and draw away from the melted metal in the interior, thus forming a cavity. Into this cavity the melted metal of the interior sinks, and continues to do so as long as a drop of molten metal remains. The result is shown in Fig. 9, which represents a 10-cwt. ingot, 36 inches long by 9 inches square at the top and 12 inches square at the bottom, cast in an iron mould. The cavity, which extends downward 17 inches, measures 5 inches by 4 inches at the top; that is, 4 cwts. of the ingot as cast are unsound, and 6 cwts. consist of solid metal. The cavity shown is altogether due to piping, and the metal surrounding it is quite solid.

This ingot of mild steel (which has ·2 per cent. of carbon) began to set on the top and outsides in two minutes, and was solid throughout in five minutes. With a large ingot of, say, 30 tons, the fluid metal in the centre would not solidify for about eight hours, and the piping would not be so far down. On the other hand, a section of metal cast, say, one inch thick would set practically during the process of casting, and there would be no piping. It will be understood that, in casting, a feeding head of sufficient size to contain all the piping has to be provided, and this must not be less than one-third of the casting, and not of less section than the part which it feeds. The removal of large feeding heads, especially on parts inaccessible to cold cutting saws, gave rise to some difficulty until oxyacetylene cutting plant was adopted. The propeller boss illustrated in Fig. 10 had two heads, each 3 feet 9 inches long, and 18 inches at the thickest part. The time taken to remove each of these was 20 minutes, with a consumption of 324 cubic feet of oxygen, and the cost of this, with the small quantity of acetylene used, was 10 shillings. An operation of this kind recently undertaken was the cutting of the breech of a 15-inch gun. The metal in this case was 24 inches thick, and the length 5 feet. I learn that 27 inches thickness of steel has been successfully cut by the oxy-acetylene process. In castings generally about $\frac{1}{4}$ inch of excess metal has to be left, and an objection to the oxy-acetylene process is that the part in contact with the flame

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is burnt and becomes hard. This calls for removal by the electro-welder.

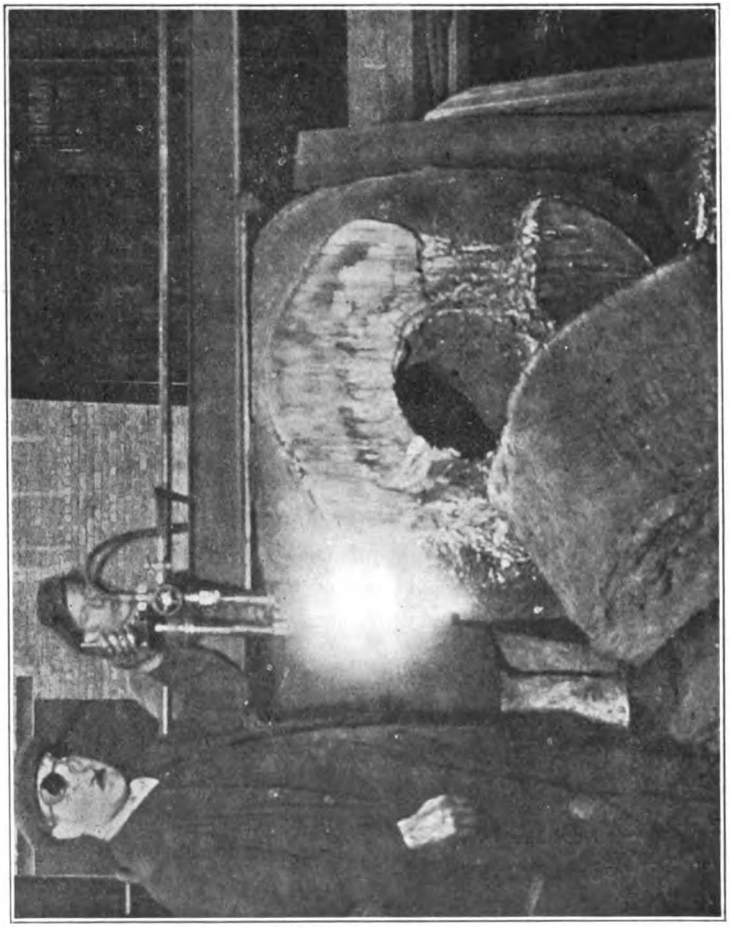

FIG. 10.

The operation of oxyacetylene cutting, when a guiding machine is used, is performed with great exactness. A certain line can be followed with an accuracy of within $\frac{1}{16}$ inch, and the profiling machines effect great saving. I understand that

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it has even been possible to cut out teeth in wheel blanks. Coal gas, though slower in operation, is now being used in place of acetylene gas, and I believe it will be possible largely to replace oxygen with high-pressure air.

The contraction of steel from the molten stage to cold metal is from $\frac{1}{5}$ inch to a foot. From experiments I made, I found that practically half the total contraction takes place during the cooling of the metal from the hottest fluid condition till just at the point of setting, while it is still plastic; the rest of the shrinkage from this point until cold, takes place in solid metal. The heat-resisting composition used in the mould hardens almost like concrete after drying, and this makes the question of shrinkage a very difficult one for the steel founder. To illustrate this, I show, in Fig. 11, a small stern tube, 14 feet long by $11\frac{1}{4}$ inches outside, and $9\frac{1}{4}$ inches inside diameter. In this case there was a difference in length between the cast and the finished lengths of nearly three inches. The main thickness of the tube being one inch, the metal set almost immediately. The tube was cast on end to permit of free shrinkage as far as possible, and the core made soft to yield to the contraction towards the centre. There are two belts of thicker metal on the casting, and the method of bracketing to prevent the quicker-contracting thin metal drawing apart from the still liquid, or plastic, metal is shown. These ribs, which are of a section to correspond to the thinner metal, set quickly, and prevent fracture of the parts they protect. It is to be observed, however, that, owing to the unequal times of contracting, the casting when cold is in a state of great tension, and the ribs must be kept on till after the casting has been annealed. It is of the utmost importance, in dealing with castings liable to fracture during the process of cooling, that the materials from which the steel employed is made be free from excessive impurity. Sulphur is especially hurtful, because its effect begins when the metal is hot and in a condition of little strength.

Thirty years ago steel propellers and propeller blades were much in demand, but a serious objection to their use was their

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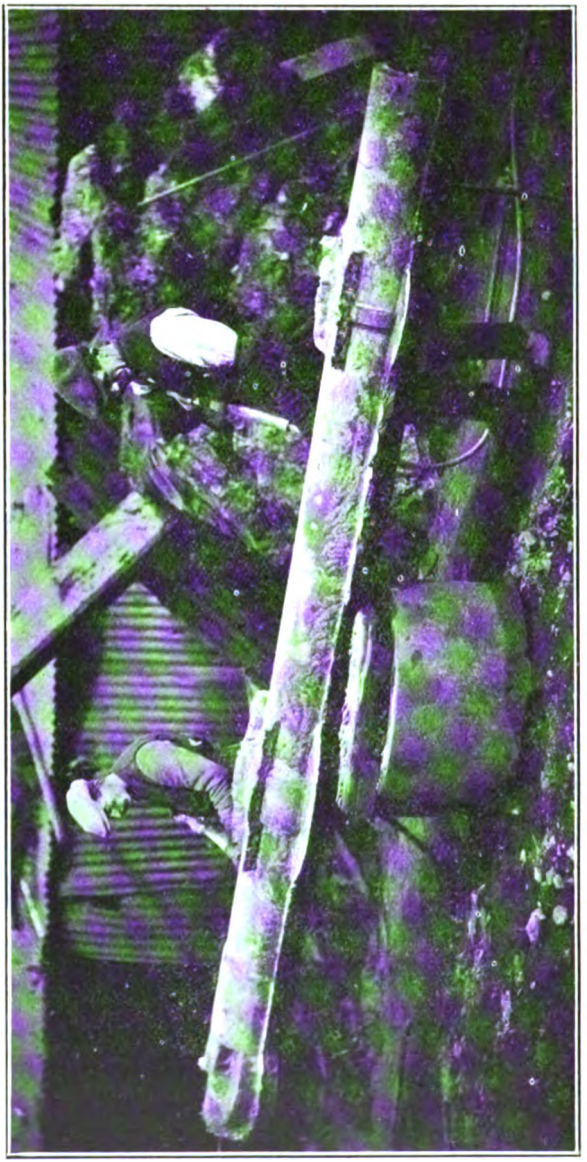

Fig. 11.

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short life, owing to pitting caused by cavitation. The advent of bronze propellers offered many advantages, and lessened the demand for steel blades, except in cases where special strength was required, such as for working in ice. Three per cent. nickel steel is an excellent material for this purpose, and has the added advantage of resisting pitting to a large extent. The ideal propeller would be one made in rustless steel, but as the advantage in price still remains with bronze, there is no demand for this material. Solid steel propellers are nearly always moulded by sweeping, and this calls for care. Only one head can be put on the casting, and this on the boss, so it requires to be both large and high. The danger points are at the junction of the boss and blades, and cracking there can only be prevented by bracketing. The propeller shown in Fig. 12 also presents a special difficulty, in that the curve and throwback of the blades hold them tightly and prevent free shrinkage. This trouble increases greatly with large diameters, and it is fortunate for the founder that these are seldom required, the boss with separate blades being most generally called for.

It may be remembered that Mr. Maurice Denny read a paper* on "Vane-Wheel Propulsion." The trials with this type of propeller showed a very high efficiency. Fig. 13 illustrates one of his vane castings, which has a diameter of 8 feet 2 inches. The conditions in casting are similar to those of a steel propeller.

Geared wheels and wheel blanks offer some difficulties in casting. The first risk with such castings, especially when large in diameter, is distortion in cooling, which results in the wheel becoming oval. A special danger point in blanks is in the rim at the junction of the arm, the lighter section of these tearing away from the heavier still fluid metal of the rim. A method of counteracting this, which is quite successful, consists in placing cast-iron chills in the moulds opposite these places. The chills are of sufficient thickness to cause the metal in the part of

* Trans. of the Institution, vol. lxvi, p. 201.

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the rim to cool uniformly with the arms. A large wheel or rim cast in halves introduces another difficulty. In cooling, the ends draw out, due to the strains along the greater outside diameter after the metal has set. In a 10-foot diameter ring

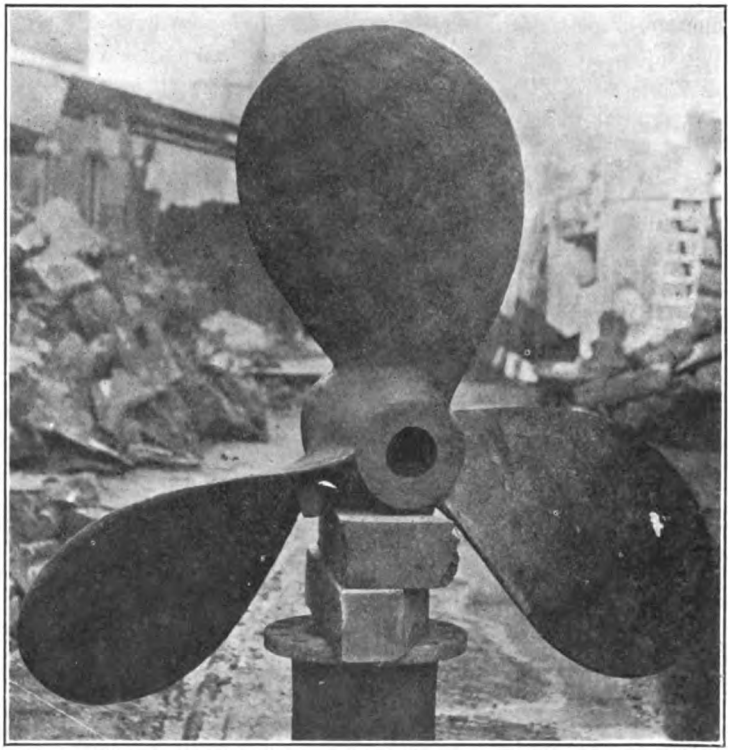

Fig. 12.

cast in halves, an increase of two inches in the diameter may be caused in this way. This may be overcome by moulding out of truth to this extent.

Castings in connection with Belleville boilers were about the first to tax the ingenuity of the steel founder, but by the time this type of boiler went out of favour such advances had been made that reliable castings were readily produced. At

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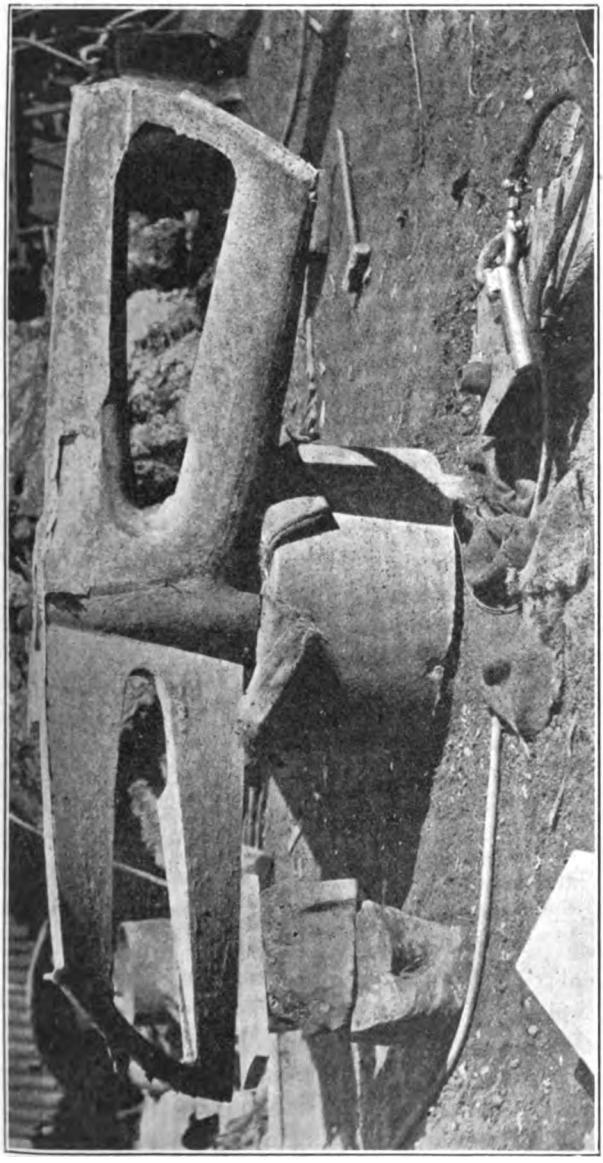

Fig. 13.

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first there was some trouble, from the steel founder's point of view, in producing sound castings of valves and pipe connections, required in large quantities by the British Admiralty. The trouble with the first valves lay in uneven thicknesses of metal, but with this difficulty removed the making of sound valves came to be a matter of careful moulding and the employment of suitable metal.

A difficulty arises in connection with intricate castings of light section, such as valves, in providing test pieces. All surveys call for test pieces to be cast as an integral part of the casting. This can only be done by casting the bars at the side, with a connecting attachment, so that not only is the casting endangered, but the metal comes to the test piece through the casting, and so is chilled and runs sluggishly. Consequently, good results are not obtained in this way, and the test piece is not representative of the casting. Under these circumstances, I think a departure from the present method of testing light castings might be made in favour of separate furnace charge test pieces. These could even be tested unannealed.

Comparative results of a 0·16 per cent. carbon steel show:—

	Maximum Stress. Tons per Square Inch.	Yield Point.	Elongation on 2 inches. Per cent.	Reduction of Area. Per cent.
As cast - - - -	29·18	17·66	23	29·5
Annealed - - -	29·17	18·44	31	46·1

If satisfactory results were obtained, the castings could then be annealed in an approved oven, using a recording pyrometer. The heat diagram would be submitted to the surveyor as a preliminary to making the final examination of the castings.

The pioneer steel founder had many years of bitter experience before he overcame the many initial difficulties which confronted him. At the outset no doubt many defective steel castings were produced, and as these defects were generally only discovered on machining, the prejudice against steel castings may be said to have had reasonable foundation.

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The steel founder, however, has managed to survive, and now turns out a product which is quite as reliably sound as iron castings, and almost as strong as steel forgings.

During the past five years the industry has suffered more severely perhaps than any other in the country. The Washington Convention reduced the Admiralty requirements to small dimensions, and the rates of exchange, longer hours, and lower wages of European competitors enabled them to get a firm hold on British markets. In 1924 the large castings imported principally from Germany and Czecho-Slovakia, and light castings from Holland, amounted to 6,641 tons, and of this quantity—

Belgium	supplied	3,414 tons.
Germany	„	1,645 „
France	„	149 „
United States	„	191 „
Netherlands	„	207 „

At the exhibition in Dusseldorf, German steel founders made many enticing offers to induce British engineers and shipbuilders to accept their products. But this competition died away, as not only was it recognised that British steel castings were better, but deliveries by Continental makers within a reasonable time could not be guaranteed. At present, however, it must be admitted that the large, well-established Continental firms turn out castings which are at least quite as good in quality of material and moulding as those of any British firm. Indeed, in some cases, they seem to find special favour in this country. I had the assurance of a managing director of a large engineering concern at Newcastle that, even before the war, he would get his steel castings, without consideration of price, from no other firm than Krupp, of Essen.

Not a few of our Clyde firms have also yielded to the temptation of lower prices. The wisdom of this is open to question. It is essential for the success of the shipbuilding and engineering industries that subsidiary manufactures, of which steel founding is one, should be in the position to con-

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tinue to supply their products, and it may eventually be found that the temporary advantage has been dearly bought.

Any paper dealing at the present time with statistics of a basic industry such as steel would not be complete without some pronouncement on Britain's ability to counteract the fierce competition of Continental firms. In 1924 Germany, having stabilised her financial position, set herself the task of organising her internal and external trade. As regards steel, this was relegated to an association called the "Rohstahlgemeinshaft," the primary object of this organisation being to regulate production in relation to the existing demand, and to fix prices. To make this effective, it was necessary to embrace not only Germany but all the steel-producing countries of Europe. After many conferences, an agreement was drawn up, and signed in September, 1926, by Germany, France, Belgium, and Luxemburg, the allocations of production being, in the first instance—

	Per cent.
Germany	40·45
France	31·89
Belgium	12·57
Luxemburg	8·55
Saar { Germany, two-thirds; France, one-third }	6·54
	100·00

In December, 1926, further conventions brought Austria, Hungary, and Czecho-Slovakia into the agreement, the whole organisation being controlled by Germany. Britain, the only remaining great European steel-producing country, stood aside in an attitude of friendly neutrality, preferring to encourage and develop her external trade with her colonies and possessions, of which India was her best customer, taking, in 1925, 480,801 tons of steel. But the advantage to the Continental combine of the German organisation soon became apparent, especially in the case of exported material, to which special preferences were given. The general effect was that Britain

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found herself quite unable to submit economic prices to the world's markets in competition with Continental makers. A comparison is given of the position at the present time:—

	British.		*Continental.*
	Home Price, delivered locally.	Export, f.o.b. Glasgow.	Export f.o.b.
Steel Ship Plates	£8 2 6	£7 12 6	£7 0 0
„ Sections	7 12 6	7 2 6	4 10 0
„ Bars	8 12 6	8 2 6	4 13 6
„ Billets	-	-	4 5 0
„ Sheet Bars	-	-	4 7 6

The disparity between prices of sections, bars, billets, and sheet bars is overwhelming, and the outstanding feature is that, while in the last few years the large British companies working on steel alone have lost money, the German steel companies have declared huge profits. Undoubtedly the Continental combine is making a strong effort to capture British markets, and kill her steel industry as a whole. But can Britain afford to let this happen? It will be remembered what an important part steel production played in winning the war. Steel-makers have brought before the Government the perilous nature of the position, and the Board of Trade has been called in to consider and advise. Belgium's official explanation is that she is able to produce steel more cheaply than Britain because her plant is more modern, and her workmen get less wages (30 per cent.) and work longer hours. On the face of it, this is quite a sufficient explanation. British users of Continental steel should, however, not forget that, with the stoppage of British steel production and the elimination of competition, there is no guarantee that the Continental combine will continue its apparent benevolent policy in respect to Britain.

It is said that British steel-makers have not brought their plant up to the same efficiency as their great rivals in the United States, Germany, France, and Belgium, and it is probably true that the difficulty of finding money for fresh capital outlay has retarded development of British steel-works during the

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last five years. Suggested remedies are all on the basis of reorganisation which should take the form of amalgamation in groups and the closing down of inefficient works, leaving the best equipped to work at their full capacity. Some alleviation of burdens is also called for; local rates and taxes under existing valuation scales press especially hard, and call for remedy.

The capitalist has reason for hesitation in investing in "industrials," when ahead of the ordinary return for his money ranks this appalling incidence of rates and taxes, so Government stock offers a greater inducement for investment. In some cases dissatisfaction with the use to which the money collected from taxation is put, and the uncertainty of settled labour conditions, have been instrumental in sending capital abroad for investment. Transport charges are far too heavy, but as the railways do not pay, and further consideration of this point leads to politics, it only remains to state that in comparison with Continental transport charges Britain is enormously handicapped. British railway rates on coal average 3s. 8d. per ton, being 83 per cent. in excess of the 1913 figure of 2s. per ton, while German rates have only increased by 41 per cent. A comparison of the present transport charges on coal with those in force before the war shows that in South Wales the percentage increase is 87—from 1s. 8½d. to 3s. 2½d. The percentage increase on the Forth is 75, and on the Clyde 71. Taking account of the tonnage shipped at the various ports, the average transport charge in 1913 was 1s. 11½d., and in 1927 3s. 5¼d. In contrast to this, it should be noted that the index number of wholesale prices is only about 40 per cent. above the pre-war level. Further, the railway rate for export coal from a Scottish colliery to Glasgow, a distance of 35 miles, is 3s. 7d. per ton, and to Bo'ness, a distance of 18 miles, 2s. 6d. per ton, while from a Polish colliery to Danzig, a distance of 375 miles, the rate is 4s. per ton.

On 1st September last, a British steel combine offered rebates off steel prices, ranging from 5s. to 7s. 6d. per ton, to users who undertook to employ only British steel. This is a

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distinct advantage to the consumer, and it is to be hoped that the larger outputs which it is anticipated will result from this scheme, will go some way in the direction of cheapening the cost of production. How Britain will fare in this industrial struggle of competing nations, it is difficult to forecast. No doubt Britain has many advantages. It is an island, no part of which is far from the coast, where there are good harbours. There are coal, iron ore, and limestone in close proximity to one another, so that the making of iron and steel should be cheap; and the works are close to the harbours, so the cost of carriage of both the raw and finished material should be light. In Germany and the United States the raw materials have to be assembled from great distances, and when manufactured they are far away from the harbours from which they have to be shipped. No doubt the rate of carriage of the goods per ton per mile is much lower in America and on the Continent than in Britain, but when transport distances are taken into account, the total sum to be paid for carriage is less in Britain than it is abroad. Then, though we all revile our climate, I doubt if there is any other place where work can be carried on outside for more days in the year than in Great Britain. We have an industrious body of skilled workmen as good, if not better than any others in the world, and our leading works are well organised and up to date.

The great trouble with industry in this country is the political interference, and misguided labour leaders who hamper the workmen. After all, there is no more common-sense man in the world than the British workman, and I have no doubt he will in time see that it is in his interest to do his best and help industry. Even politicians may yet recognise that, for the benefit of the country, it is better to leave industry alone to work out its own salvation. With a better understanding between employers and employees, I have no fear for the future of our heavy industries. It is only some 30 years since trade unionism began to give trouble in British industry, and, after all, 30 years is but a short time in the life of a nation. We have come through the greatest war in history, and last year

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we passed through the longest strike on record. After such occurrences there is bound to be great disorganisation, from which it takes time to recover; but of our ultimate success I have no doubt.

Mr. A. J. Campbell (Retiring President): Gentlemen, it is now my pleasant duty to move a vote of thanks to our new President for his inaugural address. Mr. Moore has pointed out that this is the first occasion on which the office of President of the Institution has been filled by one who has been professionally associated with the work of the metallurgist. I am sure you will agree that it has been too long delayed.

I was very much impressed by the references which Mr. Moore made to foreign competition. We all know of the endeavour which has been made to get steel users in this country to encourage the manufacture of steel at home by accepting rebates of 5s. and 7s. 6d. per ton. Many people have said, without giving the matter much consideration, that these rebates are thoroughly inadequate, and that foreign competition must go on. Our President has pointed out that if it continues there is no doubt as to what the end will be; we shall ultimately be placed completely in the hands of foreign manufacturers of steel, and once that happens we shall suffer by having to pay increased prices to the foreigner.

A few days ago I had occasion to look into the question of the quantity of steel imported into this country in proportion to the material used in our own business, and I found that, in the year 1913, in steel sections and bars, in plates over one-eighth inch thick, and plates under one-eighth inch thick, the amount was about 292,000 tons, while for the first seven months of this year the amount imported was 407,000 tons. If that continues, it is quite apparent that we shall be importing three times the amount of foreign steel that was imported in 1913.

I think the time has now arrived when both the users and manufacturers of steel should get together and take into consideration the whole question of the production and use of steel

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in this country and for this country. Mr. Moore has explained how this cartel arrangement has gathered together practically all the manufacturers and users of steel on the Continent, but we have still the Colonial markets, and it is time that the question should be fully considered with a view to giving up entirely the use of foreign steel and carrying on in our various works with the home product.

I have used this occasion to talk seriously on a question which, I think, is of first importance, and I hope that it will receive the attention it merits before all hope is lost. However, whatever your views may be on the subject which I have tried in a brief way to ventilate, I think we are highly indebted to our President for his excellent address, and I now move that we accord him our most cordial thanks.

Mr. HAROLD E. YARROW, C.B.E. (Past President): It is with great pleasure that I join with Mr. Campbell in thanking our President for his interesting address. We are indebted to Mr. Moore not only for his address, but also for the many services he has rendered to the Institution. The name of Moore will always be associated with the welfare of our Institution, because of the valuable assistance which our President and his brother, Dr. R. T. Moore, have ungrudgingly given in the past in promoting its interests. I have much pleasure in seconding the vote of thanks.

The vote of thanks was carried with acclamation.

The PRESIDENT: Many years ago Prof. Veitch, my logic professor, used to quote the wise saying, "There is nothing new under the sun," but he added, "but a fact put before us under a new light is for us a new fact." I trust that I have put before you some facts under a new light, and that they will lead to further consideration on your part.

I thank Mr. Campbell and Mr. Yarrow for their very kind words, and you, gentlemen, for the cordial reception you have given me.

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THE INDUSTRIAL ENGINEER

By Alfred J. T. Taylor,
Member of the Institution.

4th October, 1927.

The Industrial Engineer's important place in the engineering profession and his value to industry has not been generally recognised. This paper has been written to show that, if he had proper encouragement and support, he might render immense service to British industry, especially in textile mills, sugar refineries, breweries, dyeworks, and all similar industries using steam for cooking or other processes, which form a large and important part of the industrial activities of this country. The man who should have supervision of the design and operation of steam plants essential to these industries, and have an audible voice in the organisation and conduct of all the processes that depend upon steam and power for their economical working, is what, for the purposes of this paper, I shall call an Industrial Engineer. The term is not, of course, to be confused with that of efficiency engineer.

To avoid any misunderstanding at the outset, let me say that, in emphasising the importance of the industrial engineer, I have no intention of slighting any of those able men in other fields of steam engineering who, from time to time, have dealt with industrial problems. Nor would I minimise the value of the central-station engineer, who often has to work in the industrial field, but who seldom recognises that the two types of engineering are widely different. Nor would I suggest that there are no able industrial engineers. As everyone knows, some of the best in the world are here.

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Very little has been written or spoken about industrial steam engineering as a distinct branch of the profession. Direct and often mistaken criticism has been levelled against our industrial plants. Much has been said about their inefficiency. Some critics would have a wholesale scrapping of industrial steam plants. Lamentations are heard all over the country about the coal that is being wasted. But there is abundant evidence to show that the real problem of the industrial plant is not generally understood. The truth is that efficiency, as reflected in the saving of fuel, while of prime importance in a central electricity station, is of minor, and sometimes of no real, importance in an industrial plant. The important thing is the economical production of whatever goods the factory in question has to manufacture. The real object of industrialists should be to develop engineers who, instead of having only an efficiency—or rather a B.Th.U.—point of view, have as well a production—or an £ s. d.—point of view, and who are capable of relating whatever is done, or proposed to be done, in the factory steam or power plant, or in the heat or power consuming apparatus, to its ultimate effect upon the profits of the company concerned.

To emphasise this point, I have taken a diagram, Fig. 1, from the 1925 Report of the Committee on Power and Generation, of the American Institute of Electrical Engineers. This diagram is reproduced through the courtesy of Prof. A. G. Christie from his paper, "The Trend of Steam Power Plant Development," and shows the trend of those items of fuel, maintenance, labour, and fixed charges which go to make up the total cost of generation power.

These curves indicate a definite upward trend for fixed charges, while the fuel cost shows a downward trend, due partly to the increasing efficiency of the newer stations and to reduced coal prices. The last point on the curve indicates that fixed charges to-day are almost double the fuel cost per unit of output.

These considerations indicate that the foremost problem now confronting designers is the reduction of initial investment in

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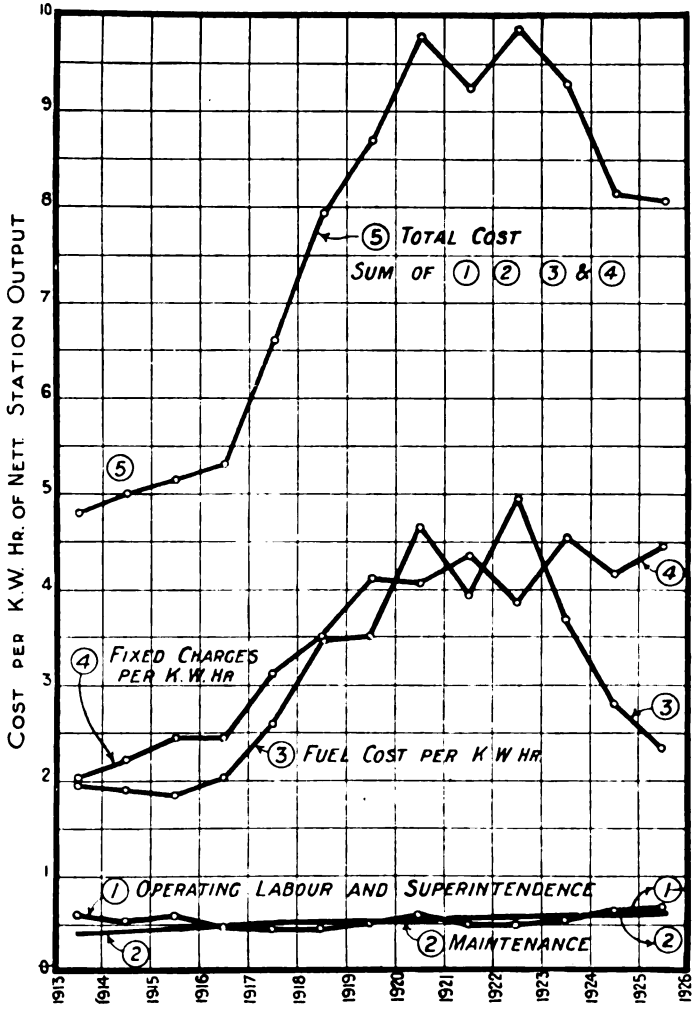

Fig. 1. Trend of Operating Costs and Fixed Charges for some typical American Central Stations of 60,000 kw. capacity and higher.

the plant, so that the curves for fixed charges and total cost may be turned downward. This desire to reduce fixed charges is having a modifying effect on the trend of steam-station

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design, particularly in endeavours to secure increased output out of standard equipment and to reduce building volume.

Let there be no misunderstanding in regard to my view of efficiency. Coal, of course, must not be wasted, and getting the utmost value in steam and power produced from every pound of coal burnt should be strongly insisted upon. But in the factory power plant let efficiency be kept in its proper place, that is, as secondary to the economic production of goods.

No one seriously questions the ability of British engineers to do the things they wish to do. The problem is to see clearly all those things that ought to be done. In the extremely rapid changes that have taken place in industry during the past 15 years, and in the disruption due to the war and its consequences, the development of an industrial engineering conscience and a recognition of the real differences between the central-station engineer and the industrial engineer have been delayed. Let me explain that fundamental difference.

Stationary steam-plants can be broadly divided into central stations, where the output is electricity, and industrial stations, where the output is steam and sometimes power. It is important to show why, when the steam-plant equipment is for the most part identical in the two cases, there is, nevertheless, a wide gulf between the functions of these two classes of station. The central-station work has naturally attracted the best engineers, the plants are large, the salaries usually good, and the engineer's influence among his fellow-citizens is generally considerable. So to-day the limit in central-station design, with the materials and pressures presently available, is being approached. There is no anxiety about the future of central stations. Capable consultants, progressive manufacturers, well-financed owners, and a rapidly expanding market for electricity at good prices, with an almost unlimited supply of engineers anxious to undertake central-station design or management, ensure this future. Great associations of executives who frequently exchange experiences, and an excellent

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international feeling between central-station engineers of all countries, have contributed to produce central stations that may now be said to manufacture one kilowatt-hour of electrical energy on a heat consumption of 15,000 B.Th.U's. or less.

Competition among manufacturers of equipment is largely responsible for progress in central-station design. The desired end is apparent—to produce electricity at the minimum cost. The consulting engineer renders valuable service in determining many factors before the station is built, such as its size, location, and probable growth. He adjudicates between competing builders of equipment so that his client may receive what is best for his conditions at the desired time. Then, again, competition is responsible for the increased size of units and their increased efficiency by the use of higher pressures and temperatures, and also for lower capital costs. Witness the new 160,000-kw. turbo-generators for Hell Gate Station, New York, followed by a 208,000-kw. set for the State Line Station, near Chicago. Only last week one of the largest European builders of turbines said that he was prepared to accept an order immediately for a 320,000-kw. set whenever it was required.

From the professional standpoint, the obvious inference is that central-station work will be less attractive to thoughtful young engineers as it becomes more standardised. It is almost axiomatic in engineering that the less original thought is required, the smaller the remuneration to the thinker will be. For this reason, our young technical men should have their attention directed to industrial engineering and its possibilities. The central-station field is being overcrowded, while the industrial field is being neglected. Some of the finest central stations of the world will be seen in this country during the next few years, but their advent will not lessen the necessity for industrial engineers, nor have any appreciable effect in reducing the cost of products from those industries with which this paper is concerned.

If the industrial problem were simply to design and build economical steam-plants, the central-station engineer could

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handle it perfectly. But that is not the whole problem; it is only one part of it. The proper relation of the steam plant to the particular industry is the vital thing that calls for more than the ordinary technical knowledge of the steam plant itself, and requires the special experience of the industrial engineer. This country has scores of able steam engineers; the whole world is short of competent industrial engineers.

The fact that the industrial steam-plant equipment is similar to that in a central station, is largely responsible for the mistaken belief that the problems are identical in each. It is supposed that, because one plant is on a smaller scale than another, the man in charge of the industrial steam-plant need not be so well trained technically, and that he can be set to produce steam or power, often without regard to the peculiarities of its consumption in the plant. Moreover, he is usually paid a wage considerably less than that paid for similar work in central stations. Plainly, the necessity for an industrial engineer, who must be a great deal more than a boiler-room foreman, has not been generally recognised. So there are numerous cases of industrial firms whose output is seriously limited by their steam plants, who often maintain a so-called efficiency in the boiler house at the expense of production, and who frequently buy power when they should produce it themselves as a by-product of their steam requirements. Such firms are found making unnecessary, and often haphazard, improvements in boiler-room equipment, and in general regarding the production of cheap steam as the desirable thing, without thinking whether the various processes in the plant are securing an adequate amount of steam and power in such a way as to ensure the maximum quantity of the desired quality of goods.

Let me repeat that adequate steam and power when and where needed are what is required, whereas efficiency, as represented in the saving of coal, is a secondary matter. Production by the intensive utilisation of the whole plant is the matter of prime importance. The industrial engineer must think of the economics of the factory as a whole, and not of

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savings in the steam section alone. He needs all the basic information of the central-station engineer, plus the knowledge of everything that requires heat or power in the industry which he serves. Some of the best industrial engineers have graduated from central stations, acquiring their special experience in industry.

It is a fact that the vital relation between output and nett profits in an industrial plant is not generally so well understood as it might be, particularly by those responsible for the engineering side of the business. With the factory closed down, there is a minimum expense which is a loss composed of fixed charges—rents, rates, taxes, and so on. As operations are commenced, the cost of labour, material, fuel, and supplies is added to these charges. Varying with the industry, it requires from 15 to 22 days of operation per month before the value of the output equals its total cost. This is in all industries the critical point. Below that certain output there is a loss, and when it is passed there is a profit; but once the critical point is passed the rate of profit very rapidly increases. Many industries, the sulphite pulp industry for one, usually operate with an output beyond the critical point representing about 10 per cent. nett profit. If the output can be increased by only 20 per cent. by methods not involving additional expenditure on plant, the nett profit in this particular industry will be increased approximately 100 per cent. The fact that the profit increases very rapidly after the critical point is passed, shows how important it is to keep the factory running at its full capacity, and also how seriously hindrances to maximum production can affect the profits of the factory.

Everyone who is in any way connected with the great industrial problems of the present day is vitally concerned with the subject of preventable losses. Broadly as well as definitely considered, all the questions of to-day depend for their ultimate solution upon a thorough and exhaustive analysis of preventable losses. The loss incurred through inefficient and insufficient production is, from my particular

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point of view, the greatest preventable loss in industry to-day, and I am firmly convinced that waste of effort cannot be checked and real industrial-plant efficiency attained until there are more thoroughly competent industrial engineers. There is no shortage of promising material from which to develop such engineers. But the industrial executive must provide the opportunities and recognise the pressing necessity in his business of developing engineers who see beyond the steam plant, and who must be allowed and encouraged to find out just what efficient use is being made of the heat and power generated there. Hitherto adequate salaries have not been offered, and full scope for initiative and a voice in the counsels of the management have not been given to such men. In this world we usually get what we pay for and no more, and we have not been paying nearly enough for our industrial engineers.

The industrial engineer is much too isolated at present. He should form associations of his fellows, at least among those in his own type of industry. They should meet and discuss, as informally and as frequently as possible, their various problems of operation and their experiences with new equipment. Members of these associations should submit problems for discussion, not to take the form of papers, but of free talks of a confidential nature among themselves. A movement of this sort should receive every encouragement from the industrial executives. Why should men operating similar plants each have to make the same original experiments and usually the same mistakes? The day of industrial secrets is over. There is more to be gained from a free exchange of experience than from special little tricks jealously guarded as in former days. Industries to prosper must broaden both their knowledge and their sympathies. The so-called good old days have passed when the individual plant owner could, and often did, defy everyone else in the same industry and follow his independent course, neither giving or receiving information. Manufacturers in other countries have learned that a free interchange of technical experience pays

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all concerned. A large share of the rapid development of central stations has been due to the adoption of this plan and to the free interchange of experience.

There is another point. Competition forces the producer not only to do his best with his own factory, but inevitably to co-operate with others, and we shall certainly see the exchange of gas, heat, and power between neighbouring factories which have a surplus of one or the other. There is sufficient importance in this one idea alone to warrant some able men giving its development their entire attention. The plan has been adopted in parts of Europe, and it merits most careful consideration in this country. Industrialists must be careful to see that legislation is not passed in this country that will prevent this free exchange of gas, power, or heat. This is not an idle warning; restrictive legislation has been passed in some countries with the view of benefiting the central stations.

Why should not a tyre mill with a surplus of, say, 3,000 kw. continuously, as a by-product of their heat requirements, send this surplus of electrical energy to neighbouring plants at a profit? Or might it not be possible to interchange power with a central station, taking power from the latter during off-peak periods and possibly at night? The central-station engineer cannot be expected to guard this possible avenue to great economy; it is for the industrial engineer to safeguard and develop.

Manufacturers of equipment usually favour the large central-station business; it gives them a greater volume of standard manufacture. The industrial plant usually needs special equipment, but standard equipment is too often purchased because it is cheaper and less troublesome to obtain, and the industrial plant suffers in consequence. Only the other day a large manufacturing firm frankly said: "We cannot be bothered making special industrial turbines because the necessary preliminary investigations falling upon us as manufacturers cost too much, and our supply of men competent to do this work properly is limited. They must be industrial

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engineers, who are hard to find. We have built no standard industrial turbines for two years; our best friends are the central stations." Yet industrial plants should, in many cases, produce their own electrical power with special turbines, and the industry itself must provide the engineers to say what is required and to see that it is furnished.

Let me repeat that the first man to consult before spending money on industrial steam-plant reorganisation is an engineer with a thorough industrial training. Executives as a class have seldom recognised the interdependence of the steam plant and the factory. They often think that the one is independent of the other. There is, for example, one plant in this country having six boiler-houses. The executive were about to scrap the lot and build a new pulverised-fuel boiler plant equal in size to the sum of the present six, when it was pointed out that the proposed new boiler house might be either too large or too small to serve their requirements properly. It was shown that the steam-recording meters throughout the plant only recorded demands for steam that had actually been supplied—not the maximum demands that might have been made and not fulfilled. Then, again, different steam-using operations might have been going on simultaneously when they could, with advantage to production, have been rearranged to follow one another. A preliminary survey indicated that, by making certain modifications, an additional boiler plant might not be required, or at least a much smaller addition might be needed than was originally contemplated.

Out of nearly two thousand studies of industrial plants made in this and other countries by myself and associates, over 70 per cent. have shown that the boiler room has been a limiting factor in production, and that some processes have suffered, or have been delayed, through an inadequate steam supply or through fluctuating pressures. These investigations further show that over one-half of the plants should and could supply their own power for considerably less than they could possibly purchase it. I can say with confidence that in any industrial plant where both power and heat are

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necessary, there are the strongest financial motives for considering the advantages of producing power as a by-product of the heat required for process. These studies also showed that the standard of engineering in the majority of these plants was below what it should have been. In many cases the engineer had no direct contact with the executive at all, and usually was asked to concern himself only with the steam plant.

The blame for these conditions rests upon several parties. The manufacturer of equipment has not a little to do with this through his incessant advocacy of efficiency. Many a good executive with no technical training will discount such talk by a process of simple reasoning. For he will say, "My total coal bill is only so much, and if this enthusiast for new boilers, stokers, or what not, saves the lot, it will not appreciably affect our dividends." The executive may or may not be right in any particular case. But he is always right in being wary of the recommendations of sales engineers who would improve his industrial steam-plant, unless they have a thorough knowledge of the factory itself. An intelligent managing director, even though non-technical, is vastly more satisfactory to deal with than a plant engineer who is fearful of exceeding his authority and ignorant of the commercial side of his employers' business.

Manufacturers in another way delay the study and solution of industrial-plant problems by sending out salesmen who only know steam-plant equipment from the central station point of view. When there are more well-informed industrial engineers, round-table conferences amongst various sales engineers competing for a given order will be possible. Then the relative merits of the equipment offered and its applicability to the case will be readily appraised. This procedure, if generally adopted, would remarkably raise the standard of sales engineering.

Industrial engineering is a branch that, for good reasons, cannot be left wholly with the manufacturer of equipment to develop. Two of these reasons are that, firstly, the manu-

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facturer is anxious to be busy with standard work, and secondly, industrial work is often not considered profitable enough in comparison with the other to encourage the manufacturer to make it a special study. This will change, and there are exceptions to it even at present. The general development by what may be called "free engineering" from the manufacturers is not sufficiently rapid to satisfy industrial requirements. Factories must supplement help from the outside by their own engineering staff.

The far-sighted executive of to-day will not hesitate to invest money in engineering brains. The best solutions to his problems are not to be found by the men of mediocre training or experience. Where consulting engineers are employed, those should be selected who are experienced and competent in industrial practice.

I think it is high time that the service which manufacturers of engineering equipment render to the entire community should be generally recognised, and that sales engineers who know their business should receive more consideration from purchasing executives. Both industrial and central-station engineering would be a long way behind to-day's level if it were not for the efforts of the manufacturers of equipment. The whole development, for instance, of mechanical stokers for the past 20 years has been brought about by stoker manufacturers. But in spite of this there are still men who, in spirit at least, are inclined to agree with the sentiment of Napoleon's time, which classed all those who made and sold things as being among the lowest forms of animal life, and who give little attention to the representations of sales engineers.

If there is one shortcoming in the present courses of technical training, it is that young engineers are not brought into intimate practical contact with all the processes in one or other of the heat-using industries. I have questioned a number of technical graduates as to the relation existing between the boiler house and, say, the half-dozen distinct processes requiring steam in a sugar refinery, and I have invariably

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found them totally ignorant of the real requirements of these processes as related to the operation of the boiler house.

A great many engineers seem to believe that, once a factory has its boiler plant, all that remains to be done is to keep it running, burning as little coal as possible, and to endeavour so to arrange the factory processes that fluctuations in the demand for steam are reduced to a minimum. Few engineers think of the advisability of increasing the fluctuations, and thereby possibly reducing the boiler efficiency, in order to get greater production and better quality goods. Yet this is the viewpoint of the industrial engineer. The steam plant must be the servant of the factory, not its master.

I may be asked why I lay all this emphasis upon the difference between central-station and industrial engineers. Let me, in reply, give some illustrations from actual practice.

The directors of a sugar refinery recently had their whole steam system overhauled by a competent industrial engineer. They increased their production by 20 per cent., practically doubled their nett profits, became independent of outside sources of power, retrieved the full capital investment made in improvements in the steam system of the factory within twelve months, and burned less coal than before, although the boiler plant had an average efficiency of over 72 per cent. before the changes were commenced. That was the work of an industrial engineer. Central-station engineers had urged the purchase of power from an outside source of supply.

Recently some engineers examined a system of submerged combustion where gas was burned directly in the water to be heated. The central-station men said, "This system is interesting, but may not be commercial for producing steam," and they were probably right. But the industrial engineer said, "This may be used for the direct heating of dye-vats and replace steam."

As a further example of how the central-station engineer might easily overlook a matter of great importance to the industrial engineer, I may mention a recent installation of a high-pressure boiler which must have absolutely pure water,

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and is generating steam at a pressure of 3,200 lbs. per square inch. This boiler is supplying steam to a process through a turbine exhausting against 90 lbs. pressure. In order to return uncontaminated condensate to the boiler, the steam at 90 lbs. pressure, instead of being used directly in some process, as is usual, is in this case passed through a heat exchanger which heats up raw water to practically the same temperature as the steam, and acts as a condenser for the steam which, as pure water, remains in a closed circuit with the boiler. This application of a heat exchanger is of little interest to the central-station engineer, but may be of great value to the industrial engineer, for it can be shown that it is economically better to operate one boiler, requiring pure water, at a high continuous rating of, say, 400 per cent., and to use this in conjunction with a heat exchanger, than it is to operate two boilers with raw water at, say, 200 per cent. rating. High continuous ratings are not possible with raw water, owing to the difficulties, among others, which develop from the concentration of scale-forming elements in the water.

The use of high pressures is frequently discussed, and almost invariably their use is associated with the central station. But it is interesting to note that a careful survey shows a marked tendency upon the part of industrial plants to go to pressures averaging between 300 and 400 lbs., and temperatures up to 700 degrees F., often exhausting against back pressures as high as 160 lbs. In isolated cases, much higher initial pressures are being used. This tendency towards higher-pressure boilers in the industrial plant is not necessarily prompted by the same considerations that have led to the adoption of higher pressures in central stations. It behoves the industrial engineer to be informed on this subject, and to understand thoroughly the benefits to be derived from the use of higher pressures.

The central-station engineer can go directly to pressures and temperatures limited only by commercial considerations and the ability to get materials that will successfully withstand the conditions imposed upon them. But when higher pressures

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are contemplated for an industrial plant, consideration must be given to the fact that the higher the pressure at which the boilers are required to operate, the less able they are to meet fluctuating steam demands, because these demands are frequently supplied not only by varying the rate of firing, but from the storage capacity of the water in the boiler itself. The popularity of the Lancashire boiler in Great Britain rests largely upon its steam storage capacity. As the pressure is increased, the storage capacity of a given volume of water very rapidly decreases, and with further increases in pressure the provision of a large volume of water in the boiler becomes seriously limited. In fact, when very high pressures are reached, there is only the minimum quantity of water in the boiler itself.

To mention one much-needed industrial steam-plant reform, I suggest that hundreds of boiler plants are limited in capacity by having chimneys of insufficient height, many of them only half as high as they should be. Chimneys are not expensive as things go, and the industrial engineer is the man to insist upon new ones. Apparently the selling of chimneys is not energetically pushed, otherwise the mistakes would have been corrected long ago. From the public point of view, short chimneys should be discouraged, on account of the dust and dirt they deposit in their immediate vicinity. The minimum height of chimneys serving boiler plants should be 150 feet, and this is fixed by legislation in certain foreign cities. Better conditions in industrial power-plants would do more for the public health, comfort, and prosperity than is generally understood. The greatest smoke and dust producers are the industrial plants, hundreds of which are very badly equipped and operated.

Many of us are tired of hearing of our technical inferiority. It is true that industrial engineers have not been trained and developed as they might have been, but it is not because it is impossible. The responsibility lies largely with the business side of industrial undertakings. Boards of directors, and especially managers, count more for or against industrial efficiency than all other influences combined. If the manage-

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ment does not realise the importance and the effect of its steam plant, and the necessity for well-paid experienced technical guidance, the solution of our problem has not even been started.

Britain's future rests with the industrialists. If she does not compete in manufactured products, she will decline. Her markets are being challenged, curtailed, and encroached upon. It is not a flattering thing for a Britisher to find, as I did a short time ago, that in Sweden, a small and somewhat isolated country, a manufacturing firm with a limited domestic market, and having no subsidies nor other outside forms of assistance, can and does, under almost ideal labour conditions, and without the sordidness that characterises some of Britain's industrial centres, actually manufacture goods, transport them across the Atlantic, jump over a high American tariff wall, and undersell the Americans in their own mass-production field. Further, it can be said with confidence that in this particular line there is not a firm at present in Great Britain which is producing the same class of goods at equal cost, in spite of the fact that the conditions under which similar labour is living in this country leave much to be desired.

Lower wages or lower standards of living cannot be expected to result in cheaper goods. These are not necessary, and are not coming in any event. British standards of living have to improve and not to deteriorate. We must look to more economic production by getting a greater amount of work per unit of labour and per unit of capital invested. The successful industrial executive to-day recognises the necessity of working hand in hand with science, and knows that, important as finance and other phases of business are, they are only part of what has become a very complex whole, in which sound engineering is an essential and important fact.

Man-power or leadership should occupy a greater place in business to-day than ever before. No one doubts our financial and marketing leadership, but there is a deficiency in our industrial engineering leadership, because the importance of the industrial engineer has not yet been recognised. Great

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Britain's position as an industrial leader depends more on the development of competent industrial engineers than upon any other factor.

Discussion.

Dr. E. G. RITCHIE: Mr. Taylor's view is certainly the correct one, that coal is one of the raw materials of industry, and should be used, like other raw materials, neither sparingly nor extravagantly, but employed to the one end of obtaining the maximum of profit on the manufactured article.

In contradistinction to the idea of finding out how to operate an industrial plant at its maximum capacity, the usual function of the industrial engineer is to keep existing equipment running with the minimum of expenditure on maintenance, until replacement is purely a matter of mechanical necessity. Apart from this, very little attempt is made to co-ordinate the various processes in an industrial operation and to balance up energy demand in its various forms. This must have an incalculable effect on plant capacity as measured in terms of output. The industrial machine is a complicated mechanism, each unit of which must adequately and completely fulfil its function if the plant as a whole is to develop its maximum capacity with the utmost economy. The most important factor in such a development is the determination and analysis of preventable losses, as Mr. Taylor rightly points out, and if we are to meet foreign competition, both at home and abroad, industrial operations must be submitted to the same scientific scrutiny that is given to the subject by our competitors, particularly in Germany and in the United States.

The large bulk of our industrialists have simply no conception of the value of scientific inquiry (I use the term in its widest sense) in relation to their manufacturing processes. This is due to lack of technical knowledge and experience on the part of the directorate, and their dependence upon the opinion of an operating or executive engineer, who has not the time and seldom has the technical equipment for carrying out research on the plant under his control. Scientific develop-

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Dr. E. G. Ritchie.

ment of the plant should be the sphere of the industrial engineer, but, if he is to do any good, he must have a free hand to carry out his investigations, and should be responsible directly to the board of management, as Mr. Taylor suggests. The right man, with adequate technical equipment, given the opportunity of carrying out plant research work along broad economic lines and in the full confidence of the management, could revolutionise most industrial processes. The common-sense application of scientific principles to manufacturing operations usually improves the quality of the finished product; it invariably leads to a reduction in its cost.

Mr. Taylor refers to the scarcity of qualified industrial engineers. This is the fault of the industrialist, and not that of the engineering schools. Under present conditions, university training is a bad investment, and post-graduate research a waste of time from the monetary point of view. The analysis of a technical problem is as skilled as a medical diagnosis, and, to be of any service to industry in a technical capacity, a graduate should spend several years on post-graduate research under a skilled research worker. Including his apprenticeship, such a man finds himself at the end of eight or ten years of non-remunerative and expensive training with little prospect of being given an opportunity of applying his special skill, and less prospect of recouping himself for the time and money spent in obtaining his training. If industry is to get out of the rut, it must encourage the research engineer by making it worth his while to devote time to the learning of his craft, and, having done so, he must be given the opportunity of applying his specialised knowledge to practical industrial problems. It is from this class that the industrial engineer should be drawn. An engineer with a university training has more tools in his kit than the purely practical engineer, and, if he has added to this a sound knowledge of the chemical and physical principles upon which engineering is built up, from actual personal contact in the research laboratory, he is a great potential asset to industry, a fact which very few of our industrialists seem to realise.

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Dr. E. G. Ritchie.

Technically, we are not inferior to our competitors abroad, but we are very definitely behind in giving technical science its opportunity.

Complaint is often made that university training is too far divorced from practical engineering needs. Actually, in these days, there is little or no time available at the universities for lecturing on purely practical work, and, in my opinion, the thorough teaching of fundamental principles, especially in physics and chemistry, is of far greater utility to the future employer of a technical graduate. All industrial processes are the application of fundamental scientific principles, and if a student understands these he will have no difficulty in following their practical application. In this connection, an immense amount of real good would result if the industrialist took a greater interest in university work, and fully realised the benefit of associating himself with members of the university staff and their endeavours. There is hardly a firm of note engaged in the engineering, chemical, and allied industries on the Continent or in the United States that does not closely associate itself with university research work, apart from the work of its own staff, and many of them have professors of engineering, chemistry, or physics on their board of directors or employ them in a consulting capacity. In this country, such co-operation is practically unknown. One way and another, British industry is losing a great deal by its indifference to the possibilities of close contact with applied and theoretical science.

The Institution owes Mr. Taylor a debt of gratitude for his excellent paper, and it is sincerely to be hoped that the manufacturer will fully appreciate the vast potentialities of the industrial engineer charged with the duties Mr. Taylor suggests.

Mr. R. D. Munro (Member): The title of Mr. Taylor's paper, so far as I am aware, is original, but the type of engineer it refers to, although perhaps not numerous, is as old as the profession. During my apprenticeship I knew of

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engineers who became part and parcel of their steam-using industries, from the stokehole to the production and despatch, and also of many others of equally good engineering training whose interests never got beyond the condensers, and who, in their anxiety to gain a decimal point in steam efficiency, would spend freely without regard to its effect on the all-round economy.

There is no specially defined method—and it is difficult to see how there can be without the co-operation of manufacturers —whereby engineers can acquire such general knowledge as will qualify them to deal equally proficiently with power plant and manufacturing processes. All the same, instances are still to be found where the engineer of the factory has mastered the details of the manufacture and become manager of the works, much to the advantage of his firm. In such cases the companies concerned were fortunate in securing the services of qualified and resourceful engineers who took an interest in matters beyond their special domain, and slowly perhaps, but surely acquired such knowledge of the industry as enabled them to obtain the best all-round results.

In one large concern with which I had a long connection, a system was introduced with the object of educating engineers in the special processses of the industry. Candidates of good education and possessed of sound practical and technical engineering knowledge were selected, preference being given to those who had chemical experience. As a result, modifications and sometimes renewals of the manufacturing plant were carried out with considerable improvement in the quality and cost of production. The more successful of those so engaged were in time made managers, or perhaps as Mr. Taylor would designate them, industrial engineers.

Some 30 years ago there was an institution known as "The Glasgow and West of Scotland Association of Enginekeepers and Firemen," which was of a purely technical character, and had no connection with trades union or friendly society objects. Candidates for membership had to pass an examination, and according to qualification were awarded certificates of first.

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second, or third degree. The majority of the members were men of, say, sixth standard education, who on leaving school drifted into steam-using factories, and grew up, so to speak, in an atmosphere of steam power and steam manufacturing processes. As President of this Association for a period, I had opportunities of ascertaining what men in such circumstances could attain to with diligence in application and observation. Not a few of them could make some modern engineers feel very humble, and several of them rose to be managers of the works in which they began as nondescripts. In one notable instance, a member gave such proof of proficiency as to justify his company in sending him to America—on the introduction of the McKinlay tariff—to erect and afterwards superintend the working of a new factory in that country.

Training in steam-using concerns such as those just referred to should, I submit, be looked upon as a department of engineering of considerable importance to the country, and it is unfortunate that those who are daily in contact with boilers, engines, and manufacturing machinery in active operation are not more thoroughly utilised, for the benefit of those who design and construct but lack the experience gained from day-to-day observation of the same in active commission.

Specialisation and standardisation no doubt possess advantages, and in certain lines of engineering are really necessary, but experience forces me to conclude that men of resourceful character, capable of taking broad views, are more than ever required in all our industrial concerns. Manufacturing firms, in their own and the country's interest, should furnish every opportunity for their engineering departments to become conversant with their respective industries, and to select only such as give hearty and intelligent response thereto. Out of such the ideal engineer would be sure to evolve.

On page 44, Mr. Taylor gives an instance of the wonderful improvement effected in a sugar refinery due to the employment of a competent industrial engineer. This, although a notable instance, is by no means exceptional, particularly in sugar refineries and dyeworks, etc., where the steam consump-

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tion for process not infrequently amounts to 70 and 80 per cent. of the total boiler evaporation. In many such establishments of ancient date, any alteration is almost sure to be advantageous, but when dealt with intelligently it usually means profit all round.

Generally, I consider Mr. Taylor's paper comes very appropriately at the present time, when co-operation in all that is best in industry is so necessary for the welfare of the country.

Mr. H. Weilding: Mr. Taylor deals with a very vital arm of Britain's activities, and I feel that I cannot adequately enough endorse the principles of his paper. He makes it quite clear that there is no intention of slighting men in other fields of steam engineering, or central-station engineers, for the activities of all these are equally important. It is quite true that a great deal has been said about the inefficiencies of industrial plants, and while there is ground for much criticism, there are some industrial plants operated on really sound lines. It is obvious that the successful operation of such plants rests with the industrial engineer, just as the successful operation of a large central or superpower station rests with the central-station engineer.

Regarding the lamentations that are heard about the waste of coal, it is quite true that wanton waste goes on daily at only too many of our industrial works, due to the fact that the real problem of the industrial plant is not understood. I have very vivid recollections of the coal economy campaign during the late war, having had to inspect and report upon the general conditions of operation of over 100 industrial plants in a particular area. It was this experience that made me feel that the industrial engineer must wake up and put his house in order, but before this can be done industrial engineers will have to be developed. The Electricity Commissioners look after the thorough and efficient development of central or superpower stations. Why should there not be a similar board for the benefit of industrial plants?

The high efficiencies that are obtained in all our central

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and superpower stations are well known, but I am of the opinion that at least the same degree of success could be generally obtained from our industrial plants if the necessary attention were given to the matter. I have a case in mind at the moment with which I am directly connected, where at an industrial station the steam or heat required is more than double that required for power, and by putting this plant on up-to-date lines a saving of 2,000 tons of coal per annum could be effected. There may be thousands of similar cases throughout Britain, and as coal is a vital asset of our existence, it is imperative that the real industrial engineer be available to take part in coal conservation.

I agree that there is no anxiety for the future of central stations; this cannot, at present, be said of our industrial stations. Central stations can, more or less, be standardised, and there are at the present time many repetitions; but standardisation of industrial stations is almost impossible, as there is such a variety of demands for both power and heat. It is my opinion that before long the young, able technical men of the country will direct their attention to the possibilities of the industrial station.

There should be no doubt about the efficiency of the boiler house in an industrial station, if eyes and thought are kept on the path of the steam used for process work, so that the latent heat is utilised instead of being given up in the condenser of the power-generating plant. This, to my mind, is a point of which the fullest advantage should be taken, and while there is to-day, in central-station work, a quantity of steam passed out for feed-water heating, it is very small compared to some of the heat required at many industrial works. It is quite true that the industrial engineer has to think of more than the steam section, and it is more than wonderful what progress can be made in the transmission and application of power to industrial machinery. I have quite definite information of production being increased from 5 to 10 per cent. without affecting the coal consumption. There are 101 things, all of importance, which come under the direct notice of the

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Mr. H. Weilding.

industrial engineer, and all these go to the ultimate success of the particular production. An association of industrial engineers would undoubtedly be a useful asset to development. The capable industrial engineer is undoubtedly the man to safeguard and develop the ways and means for the efficient and profitable production at his particular works; he will take care of by-products; in many cases the power required would be a by-product of the steam generated. In the case which I cited of a saving of 2,000 tons of coal per annum, the firm were advised to put down two additional boilers, but instead of doing so they made power a by-product of steam, and have a good margin in their original plant, complete with a continuous supply of process steam, which continuity is vital to the particular production.

Practical contact at any of our industrial works counts for 50 per cent. or over of the efficient operation. It is interesting to see how production at a sugar refinery was increased to the extent of 20 per cent. and the profits doubled, but I am not at all surprised. Steam accumulators equipped with wonderful valve gear can now be obtained which will deal with steam at any required pressure, and so keep the boilers at a fairly constant and efficient rate, giving the necessary steam for any particular requirement.

Mr. David Brownlie, B.Sc.: My main criticism of Mr. Taylor's interesting paper is that he does not put the case for the industrial engineer as strongly as I feel sure he is able to do, by including, for example, the evil influence of the politician, of all schools and colours. So many facts and experiences can be cited in support of Mr. Taylor's contentions that it is unfortunately impossible to do justice to the matter in any reasonable amount of time. I am myself interested mainly in two sections of industry, both interdependent, namely, steam-boiler plant practice and low-temperature carbonisation, using the latter term in the very broadest sense of the utilisation of raw fuel on scientific lines, especially as regards liquid-fuel production.

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Mr. David Brownlie, B.Sc.

As Mr. Taylor says, we have some of the finest engineers in the world in Great Britain, which applies equally to the general workman, the inventor, and the ordinary managerial staff, but in the above two vital sections of fuel technology we are being rapidly outclassed to-day, alike by the United States and Germany. The main reason is, to put the matter bluntly, that in Great Britain the men at the top generally are not big enough for the job, a fact that is becoming more and more apparent as the times, especially in regard to engineering, increase in complexity. It is mainly for this reason that the industrial engineer continues to be treated in the manner that Mr. Taylor so ably outlines, and I can support him from a personal experience of inspecting over 2,000 boiler and power plants in over 50 different industries in Great Britain.

As far as the politician is concerned, he, in my opinion, is one of the worst enemies to-day of the engineer, both directly and indirectly, and the situation is strikingly illustrated by the 1925 Fleet Order. It is almost beyond belief in these modern times that the British Government should deliberately debase the status of the engineer, on whom the whole fleet depends, and a careful consideration, for example, of Captain Onyon's recent Presidential Address to the Institute of Marine Engineers reveals an almost incredible state of affairs. Mr. Taylor quite rightly emphasises the necessity of the industrial engineers to combine, and this lack of co-operation, another of the greatest defects in our national life, is well illustrated by the fact that the engineers of Great Britain, both on land and sea, will take, lying down, episodes like this Fleet Order.

The politician in the same way is hampering engineering and technology in all directions, especially when the development of the resources of our own country is concerned, and as examples we may take low-temperature carbonisation, the Severn hydro-electric scheme, and the Channel Tunnel, all of which are being successfully obstructed, just as in the case of anti-black smoke legislation.

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Mr. David Brownlie, B.Sc.

Mr. Taylor says the world is short of competent industrial engineers, especially as regards power plant, and I sincerely hope the shortage will continue until sufficient brains are developed to pay adequate wages. Incidentally, I do not altogether agree with Mr. Taylor when he infers that power stations are better in this respect than industrial plants. One very highly competent man I know was paid less than £350 a year by one of the largest corporations in Great Britain as scientific boiler-plant expert at a leading station, and naturally he cleared out as soon as he got a properly paid job in commercial engineering, where all his really valuable knowledge and experience was lost. The boiler plant of the average power station, in my opinion, is a disgrace, and altogether there is work in this country for at least 1,000 highly-paid boiler experts to help to save some of the 20,000,000 tons of coal which is wasted every year on stationary land plants alone out of the 90,000,000 tons burnt.

I could mention many other points, but to take a final example, Mr. Taylor points out the ridiculous position to-day that a works with surplus electrical power cannot sell it. This is another result of the work of the politician, who in the past, largely because of supreme ignorance of the subject, granted to supply companies rights and privileges which should never have been given at all. In one of my own cases before the war, a certain firm of iron and steel manufacturers in the north of England were willing to spend £500,000 on a huge plant for utilising their blast-furnace gas. This would have resulted in 11,000 kw. of surplus power, but a supply company had the monopoly rights for the neighbourhood, and would only give them 0·25d. per unit, although their own average selling price was over 0·75d. Consequently, the proposition fell through, and the company went on squandering all their blast-furnace gas, and 11,000 kw., as a better business policy.

In conclusion, I repeat merely what has been stated for nearly 20 years past, that if we do not change our tactics we are doomed as an industrial nation of the first rank. I hope, therefore, that Mr. Taylor will keep up the good work.

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Mr. J. Wylie Harvey.

Mr. J. WYLIE HARVEY (Member): Apart from the merits of his paper, Mr. Taylor is entitled to the gratitude of all interested for bringing to notice the position of the industrial engineer. It is my privilege to meet the industrial engineer throughout the country, and very rarely do I find him in a position of responsibility; he is seldom consulted about the process in which his company or firm are engaged, and is invariably relegated to take instructions from some of the office staff. But when the management or his employers do consult him, it is rarely about the production on which they are engaged, but principally concerning the conduct of the steam plant.

Of course, there are various reasons for this state of affairs. First of all, his is an occupation which has been overshadowed within recent years by the more aggressive power-station engineer, and the sooner an institution such as Mr. Taylor suggests is founded for the industrial engineer, the better it will be for industry. His appointment is invariably one of the humblest, and he is seldom allowed to pass an opinion about the rise and fall of the company's production. He is not allowed to see representatives of engineering firms who are constantly presenting new appliances which may, or may not, be beneficial to his business. Indeed, on the very infrequent occasions when such liberty is extended to him, it is by the grace of some of the office staff.

There is also the larger question of taking a bulk supply from the power company or installing an independent plant, which he ought to know most about, but, as I have previously stated, he is rarely considered in the matter. The wisdom of taking a bulk supply depends entirely upon what the company or firm are engaged in. Where power is required for process purposes, obviously a bulk supply is not the most suitable. Here it would be more advantageous to instal an independent plant to drive the machinery and exhaust at a back pressure for process purposes. Such conditions exist with dyers, bleachers, brewers, flax spinners, and chemical and allied trades, and it is surprising that so many of them

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have adopted bulk supplies and find them wholly unsuited for their requirements. Had the industrial engineer been consulted, this expenditure would have been saved.

Would it be too much for our Institution or some other technical society to form an Industrial Engineers' Section? I am certain that an invitation on our part would be received gladly, and fully taken advantage of by many of the industrial engineers throughout the country. The industrial engineer, as I find him, is a hard-working official, a man, in many cases, of the highest engineering attainments who deserves well of his fellows, and it must be refreshing to him that a gentleman of Mr. Taylor's standing has been the first to proclaim his capabilities.

Mr. J. Howden Hume (Past President): Mr. Taylor's paper is most opportune, and I heartily agree with his views that the industrial problem in this country requires the most skilled thought which it is possible to bring to bear upon it. It is now time that millowners and industrialists generally realised that the properly-trained engineer is a most important member of their staff, especially if, as Mr. Taylor says, he possesses the £ s. d. sense as well as the B.Th.U. one. There are many industrial plants where the engineer who has not the £ s. d. sense points proudly to his records to show how economically he is producing steam, while all the time he may be starving the process work of the plant. If he could take the broad view, he might see that greater benefit would accrue from the production of the plant as a whole if he made larger supplies of steam available, with perhaps a drop in boiler efficiency at certain periods of the process, and the really skilled industrial engineer knows that there are methods already in use whereby he can increase or vary the steam supply without necessarily decreasing the efficiency.

Mr. Taylor's plea also for co-operation between the industrial engineers of the kind he has in mind, is worthy of the closest consideration. He points to the benefits which have accrued to the art in central stations by the pooling of knowledge

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acquired by the engineers in that great industry, and he rightly believes that by industrial engineers coming together and discussing their problems and experiences, the various processes and industries concerned would benefit to a large extent.

In cordially agreeing with Mr. Taylor on this point, I am not forgetting the chief practical difficulty which lies in the way of its attainment, and that is the strong objections likely to be raised by the millowners themselves to such a course being followed by any of their employees, owing to the mill-owners, as a rule, being in competition with each other throughout the country. On the other hand, nearly all power stations have each only their own defined area for the distribution of power, and so there is little or no competition between one station and another. As a result of this position, it has, in the main, been left to the manufacturers of machinery and the inventors of new processes quite outside the four walls of the mill, so to educate the proprietors of the mills themselves, as to persuade them to apply these improvements in their own establishments. There is no doubt that in the past the tendency has been for individual manufacturers to guard jealously and secretly improvements which they may have stumbled across, or perhaps discovered by the careful investigation of some more than usually alert employee, in the hope that by operating that improvement exclusively in their own process they might obtain some advantage over the other manufacturers in their own industry.

It appears to me, however, that this is a short-sighted policy, and while it may lead to some immediate gain to the particular manufacturer, the final outcome of keeping such improvements secret may be that the industry as a whole will fall behind in efficiency, as compared with a similar industry in a foreign country where knowledge is pooled as Mr. Taylor indicates. As, in general, this is a free trade country—perhaps unfortunately—a further result of such a policy may be that the industry will not be able to compete even in its own country with a foreign industry. The industrial engineer is

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the man more than any other who can prevent this calamity, and I would add my plea to Mr. Taylor's that manufacturers and industrial executives should recognise the value of such a man by giving him the scope and opportunity to tackle their problems, and, in conjunction with his fellows in similar industries, to discuss the difficulties experienced and the solutions tried in order that the full benefit of their collective experience may be applied to the industry as a whole.

Mr. A. P. Pehrson: In my opinion, one point in Mr. Taylor's paper deserves to be emphasised on every possible occasion by anyone who has our industrial future at heart. Mr. Taylor states that "we shall certainly see the exchange of gas, heat, and power between neighbouring factories which have a surplus of one or the other." He goes on to suggest that there is sufficient importance in this idea to warrant some able men giving its development their entire attention. Here is a state of affairs in which our Continental rivals enjoy extraordinary advantages over our own manufacturers. In this country the law does not permit the exchange or sale of gas or electrical power between neighbouring factories, even though one may have a surplus for disposal. The supplying of gas and of electrical current are privileges of monopoly enterprises, safeguarded by the State. Coke-oven gas and blast-furnace gas, valuable by-products which are being produced in increasing quantities, would materially assist many of our industries, but it is possible to see, even from the windows of a railway train, valuable gases wickedly blazing away into the air, within sight of factories which could, were it not for restrictive legislation, turn the gas to excellent use.

When the existing Gas Companies' Act was passed, the function of the gas companies was to make gas and distribute it. They are now able to procure, practically at their own price, by-product gases, and to retail them with no other liability or expense than that of distribution. The possibility of this state of affairs was not realised when these arrange-

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Mr. A. P. Pehrson.

ments were made by the State, and Mr. Taylor is doing industry a good service in bringing the matter before such an influential body of opinion as the Institution of Engineers and Shipbuilders.

Mr. Taylor insists on the need for greater efficiency in industries as an essential to the material progress of the nation, and believes that in this respect the future of Britain rests with the industrialists. He has with forceful arguments pointed out the importance of the industrial engineer in the scheme of industrial activities; he insists that his importance should be better recognised, and that facilities for his better training and education should be provided. It is probably true that the training and education of our industrial engineers has not been of the best, and Mr. Taylor does real service in drawing attention to this. A higher standard of training, with a broader and wider scope of general knowledge of the problems pertaining to industry as a whole, would result in greater vision and a broader outlook, more sympathy, and more toleration of new ideas. The man whose habit of mind is that of looking ahead, perhaps far ahead, and who schemes and plans to meet those conditions, is finding it hard nowadays to get a sympathetic hearing, and harder still to obtain practical support.

It might have been expected that Mr. Taylor, himself known to be a man of large vision and broad sympathy for the pioneer's work, would bring this aspect into prominence as a plea for a higher standard of education not only for the industrial engineer, but for all those engaged in the direction of big industrial enterprise.

Mr. Taylor relates the achievement of a Swedish firm of engineers who have succeeded in producing so cheaply and so well that, in spite of heavy freight charges and high tariffs, and with identical labour conditions to those maintaining here, they are able to compete in the American markets with their products. He further asserts that there is not one firm at present in Great Britain which is producing the same class of goods at equal cost. I wish Mr. Taylor could have stated

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Mr. A. P. Pehrson.

how it is done. He truly says that we must look to more economic production by getting a greater amount of work per unit of labour and per unit of invested capital. Nobody disputes this, but here again it would be well if he could have told us how, but, like everyone else who preaches this self-evident truth, he is silent upon this point. A close and intimate study of the organisation of the Swedish enterprise referred to, as of all other successful undertakings, would probably disclose a full answer to both questions, but I am afraid that how to achieve is, and always will be, an individual problem.

Mr. DONALD MACNICOLL (Member): I quite agree with Mr. Taylor that the service which manufacturers of engineering equipment render to the entire community should be more generally recognised. I am afraid I cannot visualise round-table conferences of various competing sales engineers, nor can I agree with Mr. Taylor that "the day of industrial secrets is over." Mr. Taylor goes on to say, "Manufacturers in other countries have learned that a free interchange of technical experience pays all concerned." Has this been found amongst manufacturers of the same equipment?

I can fully appreciate that a large share of the rapid development of central stations has been due to the adoption of this plan, and to the free interchange of experience, but these are corporations which need not fear competition. If they had to fight competitively for their existence, I do not think that there would be so much interchange. Now if a manufacturer spends time and energy on the development of either a product itself or the manner of production, the first thing he naturally does is to protect it by a patent, the measure of the value of the patent being, more or less, the measure in which it enables him to meet competition. If he cannot protect his idea, then he keeps the salient features of his product or process as secret as possible.

I agree, however, that if two competitors were adjacent to one another, one having, say, too much boiler power and the

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Mr. Donald MacNicoll.

other too little, then it would be most unfortunate if they did not link up. It is only in this sense that I can see Mr. Taylor's ideas maturing, so far as competitors in the same industry are concerned, but this is something in itself.

Mr. C. R. H. Bonn (Associate Member): There was more than a hint in previous papers read by Mr. Taylor before this Institution that he had many interesting and enlightening things to say regarding the industrial engineering problems which perplex us to-day, and we have not been disappointed. His dictums concerning industrial plant layout and management, coming as they do from one of so large and varied experience, cannot be gainsaid. For the rest, he merely emphasises what has been widely known, if not openly discussed, for some time. It has long been known that we lag far behind our principal competitors in the technical control of industry, that the low status and low remuneration given to technical men promises no good for the future, that technical incompetence in management has driven, and is driving, many of our inventions abroad for development, and that the blind impulse to exploit to the utmost without regard to man or product, rather than to develop progressively, is ruining our markets at home and abroad.

The systems of running the shops and of keeping accounts have contributed very largely to the sad state of affairs prevailing. Both seem to have evolved in order to relieve the management of as much trouble and real responsibility as possible. The resulting evils, such as nepotism, the manipulation of costs, ignorant conservatism, and departmental jealousy and opposition, are notorious, but the evil results of charging technical services as oncost are perhaps not so well known. Under this system technical services tend to be cut down with other charges, such as electricity, gas, and insurance, and it is safe to say that the consequent starving of the design offices into incompetence is the cause of our dangerous dependence upon our foreign competitors for new advances. Our rivals appear to understand the elementary fact that ideas are the

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first, and by far the most important step in production, and act accordingly.

The production of commodities is a far more involved process than merchandising. Any savage can trade; only civilised people can manufacture. The successful and progressive development of production requires minds infinitely above the mere astuteness which comprehends buying at low prices and selling at high prices. To run a manufacturing concern on trading principles is to ruin it, and that is what is too commonly attempted in this country. Those in charge of manufacturing processes must be more than psychologists, technicians, practical men, or economists; they must be an intimate mixture of all these and more. Such men cannot be had cheaply, nor will they accept positions without responsibility. To-day the more courageous start in a business of their own, but rarely on a scale which can develop trade, when they might have been absorbed by a progressive expanding concern, and helped to expand trade. Others, again, in bitter disillusionment, turn to more profitable occupations, and their knowledge and experience is lost just when it is becoming most valuable.

The defects in our industrial system were remarked upon in Dickens' time, and have been the subject of interminable discussion ever since. If deficiency in knowledge were the cause, they would have been eliminated long ago, for industrialists are now exceedingly well informed. It has been said that the "Englishman is stupid in thought but brilliant in action." Certain it is that there is in most Britishers a wholesome sanity which enables them to sense that no theory will completely fit life, that the oak of civilisation cannot with impunity be torn up by the roots and replaced by the mistletoe of dubious dogma. With us society comes before the State, and our institutions are in reality aristocratic, although democratic in form. An aristocracy establishes itself in consequence of its virtues. It maintains its power by means of secrecy and obscuration. Hence the reluctance to disclose prices and details of business arrangements, and the fierce resentment against any interference with absolute control. Can anyone imagine

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Mr. C. R. H. Bonn.

the industrial hierarchy voluntarily disposing of their only real control by inviting their staffs to attend their councils? We could as soon imagine the fall of the monarchy, and that is unthinkable.

It is certain that the present state of things will persist so long as it can be made to pay, and how long that will be no man knows. I can sympathise with Mr. Taylor, coming as he does straight from a land whose tradition is democratic, in his endeavour to improve things here, but I fancy the situation is more involved than he imagines. He has looked at the body and forgotten the soul.

Mr. E. Watson Smyth: I entirely agree with Mr. Taylor that the industrial engineer is far too isolated at present, and would emphasise the necessity for a closer relationship of engineers representing works engaged in similar manufactures. If, as Mr. Taylor suggests, meetings of such engineers could be arranged for friendly discussion, it would be a great step forward, but there are difficulties to overcome before such an arrangement could be made general. To name one, I would say that, generally speaking, the problems that confront the average works engineer are mostly of a like nature, that is, a steel works engineer will want mostly to discuss problems that are to be met with in his business, and to discuss them with, say, a chemist or an electrical engineer would probably be considered by both parties as hardly worth while. Therefore, the meeting would have to be arranged at some centre where there is a number of works engaged upon similar manufactures. This might conceivably be of little advantage to the engineer of a works situated at a distance from the greatest centre of his type of manufacture, since it would not always be easy or possible for him to get away for discussions.

One good result shows up prominently in a very much discussed issue, namely, that of large combines. It is frequently argued that large combines do not necessarily result in the supposed economies resulting therefrom being passed on to the consumers, but whether this is so or not does not immediately

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Mr. E. Watson Smyth.

concern us here. What they should do, and, in my experience, actually do, is to achieve the very object which is under discussion, namely, they bring their engineers together, and experiences are exchanged and results tabulated for the common benefit. This, in my opinion, very largely increases efficiency—a much misunderstood word—within the group.

The tendency to-day in industry is to combine the interests of all large concerns, either by direct amalgamation or by convenient working arrangements, and I am sure that this will in time go very far in helping the much harassed works engineer, to the ultimate good of the industry as a whole.

Mr. Frank Anslow (Member): I think the industrial community is indebted to Mr. Taylor for indicating the services which can be rendered by the industrial engineer, and the undoubted reduction in production costs which follows the employment of such services. I agree with his description of what an industrial engineer should be, but think he might with advantage have included the industrial consulting engineer, who, having specialised in, and devoted his energies to, industrial engineering, is perhaps better qualified than most to deal with electrical engineering problems. Further, the staff of such an engineer is a most fruitful recruiting ground for the type of industrial engineer Mr. Taylor has in view.

In regard to the availability and competence of industrial engineers of to-day, my view is that they are both sufficient in quality and quantity to meet all present demands. What is required is that our industrialists should realise that, by taking advantage of the services now available, economies and reduction in production costs can be obtained in the easiest and least costly way. Should the demand increase, there would be engineers to meet it.

In the construction of a factory the services of an architect are invariably requisitioned, and similarly in a paper works, or iron and steel works, the services of a chemist, either resident or consulting, and frequently both, are considered indispensable. Why should not the industrial engineer, either

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Mr. Frank Anslow.

consulting or otherwise, be equally indispensable to an industrial factory? I am inclined to think that the explanation is a psychological one. We are all disposed to believe that we are born engineers, a weakness shared by many industrialists, with the result that more than a fair share of time is devoted to engineering activities which could be more efficiently dealt with by those qualified by training and experience to do so.

I agree with what Mr. Taylor says regarding the efficiency of individual parts of an installation. In this connection he refers to the steam plant, but others could be taken. For instance, the cost per unit of electrical power is often considered of first importance, and rightly so, but the method of generation or purchase of power, and the way it is used, may, and usually does, have a much more far-reaching effect upon the overall cost of the finished product of a factory than the cost per unit itself.

I am in complete agreement with the statement that all factories should utilise to the full their own sources of power before calling upon an outside supply for electrical power, and I think in this connection supply authorities might, with advantage to all parties, afford greater facilities at more reasonable rates for stand-by and auxiliary supply. My experience is that such a far-sighted policy in this direction brings its own reward, because factories which are conducted on the most economical lines are those which extend, and ultimately become better customers to the supply people than if they had first purchased all their supply and neglected their own resources.

When dealing with the question of the interchange of gas, heat, and power between neighbouring factories, Mr. Taylor says "Industrialists must be careful to see that legislation is not passed in this country that will prevent this free exchange of gas, power, or heat." Legislation is already in existence which makes it impossible for one factory to supply another factory with electrical energy if it is in an area over which a supply authority has rights, unless the factories are owned by

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Mr. Frank Anslow.

the same company. I quite agree, however, that industrialists should be fully alive to the effect of restrictive legislation, and guard against its extension as far as practicable. On the other hand, there is no reason why such a works as Mr. Taylor refers to, with a comparatively large quantity of waste energy available, should not make arrangements for an interchange of power with the electricity supply authorities. This has been done, and I agree that it is one of the duties of the industrial engineer to safeguard and develop this side of the problem.

While it has something to recommend it, there is a possible objection to the suggestion Mr. Taylor makes for round-table conferences of sales engineers. There is no objection to it in a general way; on the contrary, it would be distinctly helpful, but, in regard to a specific job, it might result in restricted competition and delay developments. With a comprehensive scheme prepared by a competent industrial engineer, it can be left with the manufacturer to put forward his most suitable plant, and leave his sales engineer to describe it fully and *bring* out its good points in relation to the services required. It is then for the industrial engineer to judge the conflicting points of the competing manufactures, and select that which gives the best overall results, financially or otherwise.

I do not agree with what Mr. Taylor states regarding the attitude of manufacturers to the manufacture of industrial plant. It may be true that in times of prosperity and full shops they may wish to avoid as far as possible the troubles due to industrial plant, but in times of depression like the present, manufacturers use every endeavour to secure this class of business, and employ their own engineers in advising factory management on matters which could better be left to an industrial engineer, with advantage to both purchaser and manufacturer.

I do not wish for a moment to belittle the services rendered by the manufacturers' engineer. He is invariably an expert in his own line, and capable of giving the best advice in regard to the plant he is selling, be it boilers, turbines, or electrical

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Mr. Frank Anslow.

plant, but the weakness is lack of co-ordination. Proper co-ordination can best be attained by an engineer dealing with the installation as a whole. Is it not possible that this attitude of manufacturers does much to defeat the ideal that Mr. Taylor has in mind, the importance of which is summed up in his own words—"Let me repeat that the first man to consult before spending money on industrial steam-plant reorganisation is an engineer with a thorough industrial training"?

I would emphasise Mr. Taylor's remarks in regard to the selection of an engineer. It is of first importance to select a man who can show convincing examples of his previous achievements. It is significant of the changing views of industrialists that it is in works where periodical conferences take place between heads of departments, including engineers, that the guiding hand of the industrial engineer is most appreciated.

Mr. W. W. Marriner (Vice-President): It is very fitting that the first paper to be read this session should be on the industrial situation as it is to-day, and especially so when the author is Mr. Taylor, who has had much experience of these questions, not only here but in the United States and Canada. We remember his paper on pulverised fuel,* which showed the way in which the use of pulverised fuel should be developed more than any of the other papers on the same subject with which I am acquainted.

In his opening remarks, Mr. Taylor says "the important thing is the economical production of whatever goods the factory in question has to manufacture," and he refers to textile mills, sugar refineries, breweries, dyeworks, and similar industries, but I submit that his remarks might have a good deal of significance in relation to shipbuilding and allied industries. It was a very happy coincidence that the President's Address and Mr. Taylor's paper should have been read on the same evening, because they are, to a large extent, complementary to each other. The iron and steel trades are

* Trans. of the Institution, vol. lxviii, p. 11.

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Mr. W. W. Marriner.

in a very bad state, and there may be scope there for the activities of the industrial engineer in increasing the production of iron and steel, so that this country might become at least second in output, instead of only fifth.

It is important that every now and then attention should be called to the reason why a factory exists, that is to say, "the economical production of the goods it wants to sell," and in his paper Mr. Taylor says "in the factory power plant let efficiency be kept in its proper place, that is, as secondary to the economic production of goods." Now, as an illustration of this, in the early days of the electric drive Mr. Yarrow was laying out a new yard in London, which was described by Mr. Murphy many years ago, and one of the questions most carefully considered was whether it would be better to install an electrical power plant, and to provide a motor for each line of shafting and for some of the big machines, or to stick to the old belt drive. Any figures that could be brought to bear on the question at that time showed that the belt drive was very much cheaper and much more efficient, but having had experience of the breakdown of belts in the factory, and the confusion which arises when the main driving belt fails, Mr. Yarrow decided on electric motors, with the result that after a year's working nobody in the place had a good word to say for the belt drive; all were in favour of electricity. That is an example of where the industrial engineer, that is to say, one who takes the broad view, is invaluable. It is the convenience of the electric motor which, quite apart from any efficiency, makes it such a valuable means of transmitting power.

There is a sentence in the paper which, I think, is of special importance. It reads, "Industrialists must be careful to see that legislation is not passed in this country that will prevent this free exchange of gas, power, or heat." One great danger of a Government taking a hand in the control of any supply or of any trade is that the particular supply or trade is immediately shut up in a watertight compartment, and undue prominence is then given to increasing the efficiency

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Mr. W. W. Marriner.

of that particular supply, without taking into account the interests of other branches of industry.

This warning about the free exchange of gas, power, or heat might well be applied not only to legislation on a large scale, but also, and with a great deal of force, to individual factories, and Mr. Taylor himself does not limit this exchange to gas, power, or heat, but refers to the free exchange of technical experience and knowledge. Not only do firms jealously guard special little tricks from one another, but it is possible that, in many cases, there is not a free interchange of ideas within the factory itself. Attempts have been made to surmount this by the appointment of an efficiency engineer, and this man naturally has a very difficult position, because his sole object in life is to find fault with old-established practices.

The industrial engineer, as advocated by Mr. Taylor, is a great advance on the efficiency engineer. His object is not so much to increase the efficiency of any particular operation as to increase the co-operation among the various departments, so that the production of the factory may be increased in both quality and quantity. But how are we to begin to make use of this industrial engineer? What is the first step? Supposing that the directors of a steel works thought they could improve their production and increase their efficiency, what should they do first?

Mr. Taylor says that the popularity of the Lancashire boiler rests very largely on its steam storage capacity, and I should like to ask him if he does not think that a water-tube boiler, working with a chain grate and connected to some form of thermal storage, would be a more economical proposition.

Mr. Taylor says that no one doubts our financial and marketing leadership, and I am sure that everyone who has had any experience of the British workman will agree that his skill and potentialities are second to none. But, as Mr. Taylor points out, something more is wanted than financial experts and the best possible workmen in order to obtain the maximum output. What that something is, it is difficult to determine.

Many of our young men who are not satisfied with the

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Mr. W. W. Mariner.

existing conditions and methods of working at home are going abroad, and if I may relate my personal experience it will perhaps add some point to what I have said. My eldest son is in the wool business, and he says that while there are no better artisans in the spinning and weaving mills than are to be found in the Bradford and Manchester districts, yet after four years' experience in America he would prefer to work in that country. Another son of mine in the engineering trade, after working in the shops in close contact with the men for two years, feels that there is something wrong with our methods in this country, and he, of his own accord, has determined to go to the States in order to find out what is the secret of American management, and whether it is better than ours or not. These are by no means isolated examples. I could mention at least ten young men of my own acquaintance who have gone to the States or to Canada because they are not satisfied with the conditions in this country. Can Mr. Taylor tell us the secret?

Mr. J. W. Livingstone Jones (Member): Those who call on mills and works throughout the country realise only too surely that something is very definitely wanting, as Mr. Taylor suggests. There is great difficulty in getting into touch with one who can really get down to a serious discussion, and the difficulty seems to be the result of the departmental jealousy which usually prevails in mills. The management may be drawn largely from chemists or from those who have organising ability, and such men are not particularly keen on engineers getting too much knowledge of the actual processes of manufacture. So it is that he does not get a chance to acquire any definite knowledge of what is actually wanted in the mill, and finds his operations confined to making the boiler house more efficient, whereas far better results would be obtained if he knew more of the mill requirements. I should say that engineers ought to be more often on the board of management than they are at present. In all big industrial undertakings in Germany, the engineer and the chemist

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Mr. J. W. Livingstone Jones.

occupy very prominent positions, and it is only by such an arrangement that full advantage can be taken of their knowledge and experience. Will Mr. Taylor say how an industrial engineer should be trained?

Being one of those who attempt to sell, I am rather amused by Mr. Taylor's suggestion that salesmen should have a round-table conference before being interviewed by the buyer. Perhaps that may be feasible in America, which seems to be a land where everyone can sell something, but in this country there may be only one or two jobs and possibly a dozen competitors for the work, so we are inclined to keep a little information for the buyer only, and not give it to our rivals.

Mr. Taylor says an industrial engineer might often be quite able to advise people as to whether they should take current or generate it themselves. That point frequently requires very great consideration. For example, I know of a very large paper mill which had a big fire about eight years ago, and, when reconstructing, the company were advised to buy current from the power supply company. They did so, and paid about £14,000 or £15,000 a year for it. Later, they realised how foolish they had been to purchase current when, by installing motors, they could generate it themselves and have a surplus to sell to the supply company. I know of another case in Greenock where a company generated current themselves and sold the surplus to the supply company, who again sold it to the consumer.

These instances merely emphasise what Mr. Taylor wishes to prove, namely, that engineers are required who can carefully study their firm's requirements and give the right advice, having in mind as the primary object better and cheaper production.

Mr. Kenneth M. Sloan (Member): I am very much interested in Mr. Taylor's paper, and I appreciate his opening remark that the importance of the industrial engineer's place in the engineering profession and his value to industry has not been generally recognised. I think the definition of the

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Mr. Kenneth M. Sloan.

industrial engineer which he has given, for the purpose of his paper, is rather limited. Would it not be better to give some other term to the expert in the generation and application of steam, for the various industrial processes where steam is used either for power or for other purposes? The term "steam efficiency engineer" might be more descriptive than that of "industrial engineer." To my mind, industrial engineer, production engineer, and efficiency engineer are synonymous terms. I have never yet been able to find out the difference. It should not necessarily include the engineer who is responsible for designing the steam, electrical, gas, or any other form of power plant.

The industrial engineer should take a comprehensive view of the entire plant, to determine if the power is being economically applied, and the plant efficiently used. Such a view is essential in order that he may eliminate and prevent losses, as described by Mr. Taylor, when he says, "The loss incurred through inefficient and insufficient production is, from my particular point of view, the greatest preventable loss in industry to-day, and I am firmly convinced that waste of effort cannot be checked and real industrial-plant efficiency attained until there are more thoroughly competent industrial engineers." In an engineering shop these preventable losses are probably much greater in the processes of manufacture than in the power generating plant, and are largely due to inefficient control of the work as it passes through the various processes. For example, industrial engineers in America (where this branch of the profession is much more highly developed than it is in this country) have exposed a surprisingly low machine-cutting efficiency. A machine-cutting efficiency of less than 50 per cent. is not uncommon, and this on examination is found to be due to many causes, such as delays due to imperfect organisation, defective supply of tools and material, lack of proper instructions, and lack of understanding between management and workmen.

Mr. Taylor says again that "production by intensive utilisation of the whole plant is the matter of prime importance."

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Mr. Kenneth M. Sloan.

I should rather say that production by the *efficient* utilisation of the whole plant is the aim of the industrial or efficiency engineer. The word "intensive" is misunderstood, particularly so by tradesmen in this country. The industrial engineer may have to decide the best motive power to adopt, in which case a general knowledge of the various sources of power will be of greater service to him than a special knowledge of a particular one, because if he be a steam expert he will probably favour steam plant, and if he be an electrical engineer he may be biased in favour of electricity. An industrial engineer, from my point of view, must have an extensive knowledge of labour-saving devices and labour-saving management. He should concentrate his attention upon these two most important branches of study, rather than upon acquiring expert knowledge in any one particular branch of engineering.

The last point I would refer to is Mr. Taylor's suggestion that an association of industrial engineers be formed. What I should like to ask is: Are there not sufficient associations already in existence, which are endeavouring to extend their influence? For example, there is the Institution of Production Engineers, whose object is "to promote the science and practice and raise the status of engineers as applied to production." There is also the National Institute of Industrial Psychologists, which devotes its attention to the much-neglected study of the human element in industry. Both of these associations are endeavouring to develop the new profession of industrial engineering, and are doing useful work in increasing industrial efficiency.

Prof. J. D. Cormack, C.M.G., C.B.E., D.Sc. (Member of Council): At the outset, I would like to say that I wish Mr. Taylor had found some other term than "industrial" to describe the brand of engineer treated of in the paper. I do not make any suggestion, and Mr. Sloan offers no alternative title. I may use, however, the term "plant engineer," because firstly, it has only one syllable instead of four, and

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secondly, it defines the duties just as well as the longer title, although it is not so imposing.

Mr. Taylor states, "If there is one shortcoming in the present courses of technical training, it is that young engineers are not brought into intimate practical contact with all the processes in one or other of the heat-using industries. I have questioned a number of technical graduates as to the relation existing between the boiler house and, say, the half-dozen distinct processes requiring steam in a sugar refinery, and I have invariably found them totally ignorant of the real requirements of these processes as related to the operation of the boiler house." I am not surprised that he found them a little ignorant. If he asked a young locomotive engineer about processes in the manufacture of sugar, or a young motor engineer about processes in the manufacture of mustard, the young engineer would probably show lamentable ignorance. Further, if he examined the people in this room as to their knowledge of the manufacturing process required in these industries and in the allied industries, the making of cellulose and chemicals of all descriptions, I think the answers would not be very satisfactory.

The whole matter is that if an engineer is going to be a plant engineer, such as Mr. Taylor describes, he must be a man of wide knowledge and sound judgment. The wide knowledge cannot be attained by a young technical graduate. In most institutions a technical graduate has spent, say, nine months of each of three years on his course, and has had no practical experience. The young technical graduate of Glasgow, from the University or Royal Technical College, spends four whole winters of two terms each on his course. He may have served a full apprenticeship; all, at any rate, serve some summers in the engineering shop. If Mr. Taylor had made inquiries there, although in some cases the students might have shown a knowledge of the subject, I think he would have invariably found that they knew little or nothing of the multifarious processes used in producing articles of everyday use. The young technical graduate of to-day can

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Prof. J. D. Cormack, C.M.G., C.B.E., D.Sc.

only acquire during his stay at college some knowledge of mathematics, physics, and chemistry, and those who intend to become mechanical and electrical engineers get heat and electricity, materials, structures, and at least one additional subject, such as fuels, metallurgy, engineering economics, engineering production, technical chemistry, and so on. If he intends to become a chemical engineer, the equivalent of a full year is devoted solely to technical chemistry and the design of chemical plant.

I submit that that is quite an extensive training for a young engineer to undergo, and sufficient for the purposes of the ordinary degree. I think also that if he is expected to acquire a knowledge of any particular industry, he should be sent to take a post-graduate course in that industry, but I should like to add that even then he would not be quite the man that Mr. Taylor wants, because this young industrial engineer does not know exactly where his future work is going to lead or what branch of engineering he is going to follow. I have invariably found that he takes the first good job that he can get, and so the young engineer trained for sugar manufacturing may have to turn his attention to some other industry; it might be textile, or it might be confectionery. To my mind, the essential principle in training a young engineer is to train him on a good sound scientific basis. If that is done, and if he is taught to learn how to learn, it will go far in enabling him to pick up what he requires in his future life-work.

I find myself a little appeased when I read in the paper that "Many of us are tired of hearing of our technical inferiority. It is true that industrial engineers have not been trained and developed as they might have been, but it is not because it is impossible. The responsibility lies largely with the business side of industrial undertakings," and I can say definitely that when industrial undertakings offer good positions for sound young plant engineers, we are quite prepared to supply them.

Mr. JAMES ANDERSON (Member): Like Prof. Cormack, I do not agree with the term "industrial engineer," but, unlike him,

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Mr. James Anderson.

I do not think that "plant engineer" should be adopted. It seems to me that "commercial engineer" is more in line with what Mr. Taylor is suggesting; after all, the plant engineer is in existence to-day. I take it that the type of engineer Mr. Taylor has in mind is one who can not only determine what plant is necessary, but what is the best way of running it from the £ s. d. point of view. His particular reference to this point reminds me of a problem which was brought to my notice before the war. A certain factory had an engine of a very old type; so old, in fact, that it was standing in the firm's books as of no value. It was using about three tons of coal per week, costing, at that time, approximately 7s. per ton. The question was whether it would be more economical to install a modern steam-plant that would use $1\frac{1}{4}$ ton of coal. It was obvious to me that the saving of two tons of coal per week would amount only to 14s., and it would not, therefore, be a paying proposition to put in plant which would cost perhaps £1,000. Looking at the matter from a national point of view, however, it was obviously absurd to burn three tons of coal when $1\frac{1}{4}$ would do, but the company's engineer had to consider the interests of the shareholders.

With respect to training, I consider that the present apprenticeship system is absurd for an engineer. He spends five years as an apprentice, and for a part of that time he may be at the University or the Technical College. When he is finished, he may be a fitter or a machineman, a bit of a patternmaker and a bit of a draughtsman, and, incidentally, a very small bit of a scientist. But what does he know about commercial work? He could not draw up a specification, nor could he analyse a balance sheet, and it seems to me that the industrial engineer should know something about commerce.

I suggest, therefore, that the training for the industrial engineer, or for any engineer, should be very broad indeed. Let him have a good grounding in mathematics. No engineer is worth anything at all unless he knows mathematics well. He must know mechanics, but he ought to know more concerning the theory of steam and electricity than the average

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Mr. James Anderson.

engineer knows. When he has served his apprenticeship, he should be able to calculate whether it would pay better to put in a gas engine, a steam engine, or an electric motor, and take current from the public supply, and he ought to be able to run the plant efficiently.

Mr. GILBERT AUSTIN (Member): Mr. Taylor deserves our thanks not only for the excellence of his paper, but for putting into words what many must have felt, and calling attention to a state of things for which it is difficult to say who is responsible. The manufacturer holds the key to the situation, but he is often restricted by lack of capital, or is disinclined to interest himself so long as he is getting a normal return from his undertaking. When, however, he does wake up to the possibilities of improvement, his first difficulty is to find the engineer with the necessary experience in his particular process.

Surely it is the consulting engineer to whom he should turn for advice, yet the fact that Mr. Taylor has written this paper reveals that there is some deficiency in the supply of suitable men. It seems to me that the subject is immense, and that few engineers exist who have had the opportunity to practise in more than a few specialised lines. It is evident from the paper that Mr. Taylor himself is a specialist in steam-raising plant, and he views the subject from that, admittedly the principal, aspect, for he does not even mention the internal-combustion engine as a source of power, nor anything but coal-burning as a source of heat.

I am not inclined to agree with the two previous speakers as to the title chosen by Mr. Taylor. I think the term "industrial engineer" exactly describes the attributes of the type of engineer referred to in the paper, and he is not so much the product of a college or university as the product of experience. A college grounding is essential to begin with, but unless the opportunity comes for breadth of experience the student is apt, nay, often obliged, to specialise.

In the industrial districts of Scotland there is a remarkable

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Mr. Gilbert Austin.

distinction between the requirements of certain zones. On Clydeside, for example, there is a comparative absence of process work, and here, generally speaking, electricity should reign supreme. East of Glasgow, however, and in such towns as Paisley and Greenock, there is scope for fuel economy and process development which is both varied and extensive.

Everywhere there are signs of waste and ignorance of development possibilities, mainly because manufacturers have not been brought into touch with the industrial engineer, and, in fact, do not even know that such a person exists any more than we did before the advent of Mr. Taylor's paper.

I should be sorry to see the matter end with the discussion on this paper, and I suggest that an endeavour be made, out of the discussion, to arrive at something practical. Professional etiquette decrees that it is improper for the consulting engineer to make his "wares" known like other people, with the result that owners of all sorts of works do not know where to turn for advice. It occurs to me that the course to pursue is to take steps to utilise the talent we have, and bring the manufacturer or works' owner into touch with the specialists in his line of business. I would suggest the formation of an industrial engineers association, consisting of consulting engineers, engineering plant makers, and others interested, for the purpose of spreading information concerning the most up-to-date processes, by means of advertising, lectures, demonstrations, etc. The association would also be a bureau of information, for the purpose of giving the names and addresses of engineers or firms likely to be of service to manufacturers in their particular line of business. It would be a commercial undertaking, not trading for profit but supported by the contributions of its members I am sure the subject could be discussed with profit at some of our informal meetings.

Mr. William Brown (Member): I do not think "industrial engineer" is a proper term for the man Mr. Taylor refers to. I think either steam-saving or heat-saving engineer would be

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Mr. William Brown.

more applicable. Mr. Taylor says that efficiency, as represented in the saving of coal, is a secondary matter. Now, efficiency as represented in the saving of coal is entirely a question of design. The efficiency of the generating plant at an industrial concern should be considered in the same way as the whole establishment itself, and in the manufacture of the product efficiency should be an overall term.

Mr. Taylor also says, "Broadly as well as definitely considered, all the questions of to-day depend for their ultimate solution upon a thorough and exhaustive analysis of preventable losses. The loss incurred through inefficient and insufficient production is, from my particular point of view, the greatest preventable loss in industry to-day." A great many plants are now run on a supply and demand basis. It is wrong, economically, to overproduce. Take pig iron, for instance. A year or two ago Messrs. Baird, of Gartsherrie, had about 120,000 tons of pig iron which they could not sell, so they closed down their furnaces, although the material was probably produced efficiently. Very few firms could afford to let 120,000 tons of anything lie until somebody bought it, so that preventable or insufficient production is a term affected by the market.

On the question of legislation, Mr. Taylor says that industrialists must be careful to see that legislation is not passed in this country that will prevent this free exchange of gas, power, or heat. Now, that legislation does exist in some parts of the country at least. I have in mind an industrial concern which generated its own power, and had some to spare. A joiner who made packing cases for this particular company opened premises as near their door as possible, and made an effort to get current from them, but without success, as it was illegal for them to sell it. He had to get power from some other source, so he installed a gas engine.

I do not agree with Mr. Taylor that there is really a want of industrial engineers. What is lacking is authority on the part of the plant engineer to enable him to effect much greater

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Mr. William Brown.

savings. In one well-known company a general manager was appointed over a number of the works. This man had been a clerk, with the result that when a works managership became vacant a clerk was appointed. In another case the chemist was appointed a works manager, and the engineers were ignored. I agree with what Mr. Austin says regarding training. The great difficulty in this country is not so much the want of men as the want of willingness on the part of directors and those in authority to give younger men the power to act.

I do not think, as Mr. Anderson suggests, that it is impossible for an engineer to make up a balance sheet. It happens sometimes that the directors have to be convinced that a proposed plant is going to pay, and the engineer has to show in black and white that there will be no doubt about it paying after it is installed. Any young man who is intelligent enough to become an engineer should be able to do that kind of work.

Mr. R. B. Mitchell (Vice-President): I think that Mr. Taylor has made out a very good case for an improved type of industrial engineer, and he puts his finger on the reason why the proper type is not employed. In the past it was too often thought that the end was served when what was termed "a good practical man" was in charge of the power plant. That, it is now realised, does not go nearly far enough, and what is wanted is a man with the proper qualifications and technical training to fit him to make the very best of the plant which he has at his disposal. After reading the paper, I felt that perhaps it would have been much better to submit it to a meeting of company directors rather than to a meeting of the members of this Institution. As Prof. Cormack said, there is no dearth of young engineers well qualified to undertake this sort of work; they are only waiting for a reward or an inducement sufficient to make them eagerly take it up.

Right through the paper, Mr. Taylor contrasts the industrial engineer with the central-station engineer. I do not know

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Mr. R. B. Mitchell.

that any broad line need be drawn. Certainly the training for both branches is, and ought to be, the same, and the individual can turn his mind or his energies either way, just as fortune falls to him. I was not present when the paper was read, but Mr. Taylor drew my attention to a lantern slide which he intended to show, setting out curves of the various costs in an electricity supply station, and referred to the fact that in recent years, when plants were put down of a very much higher efficiency than hitherto, the fixed charges were liable to go up as the operation costs came down. That is quite true, and it will remain so, so long as we are content with the load factors which are to be had at the present time. Something like 30 per cent. is the average in central-station supply work, but the curve of fixed charges will take the same direction as the operation costs if we get at the load factor, and make it not 30 per cent. on the average, but something like 60 per cent., or higher. The curve of fixed charges would then take the desired direction, and would enable electricity to be sold at very much lower rates than at the present time.

I was also much struck with the point which several speakers referred to, that a company of sales engineers competing for a given order could sit round a table and discuss what was best required for a particular works. That may come with the millennium, but I do not think it will arrive before that.

Another point that relates to supply undertakings is found in Mr. Taylor's reference to the buying and selling of surplus power. That, of course, has been carried out to a considerable extent on the north-east coast by the supply company working there. They have the conditions which are suitable over the wide area which they supply. In this area there may be occasions on which power is actually purchased from a factory in a supply authority's area, but I think they are very much fewer than on the north-east coast. At the same time, however, everyone will agree that the principle is absolutely correct.

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Mr. William S. Murphy.

Mr. WILLIAM S. MURPHY: Several speakers have suggested, with a good show of reason, that Mr. Taylor might have defined his aim more clearly by another title, arguing that "industrial engineer" is too general; but none of the substitutes offered defines the subject better than Mr. Taylor's. Perhaps, however, "industrial production engineer" would more fully indicate the aim of the paper, which is mainly directed to showing that the function of engineers employed in industry does not stop at the boiler house and the engine room.

For his purpose, Mr. Taylor effectively uses the contrast to be observed between the functions of the electric central-station engineer and the industrial engineer. The sole use of the central station is to generate electrical power; that is to say, the engineer employed there has to convert as completely as possible the heat in the fuel into electricity. Many users of steam power have been induced to look upon their boiler houses and engine rooms as power stations in miniature, but the analogy is quite erroneous and misleading. One large difference comes into view at once; for while the central-station engineer sends out the power he generates to light streets and homes he does not know, and drive machinery he has never seen, the power engineer employed in industry must correlate his steam plant with the machinery it drives and the manufacturing processes it serves. Mr. Taylor admirably illustrates the contrast from various viewpoints, and hammers home the lesson that power-plant efficiency, though primary in the generation of electricity, is secondary in power-driven machine manufacture.

I wish that Mr. Taylor had, out of his extensive experience, brought forward instances in which the power plant must be subordinated to the requirements of the machinery employed, and also where steam is necessary for the conduct of the productive process. He rightly emphasises the fact that a saving in fuel signifies little to the vast majority of manufacturers. Some time ago a plant engineer undertook a mission to the paper-making industry in which the steam-plant efficiency was said to be deplorably low, and he claimed as the result of his

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Mr. William S. Murphy.

advices and the changes he effected that some paper manufacturers found their coal bills reduced by 20 per cent. Roughly calculated, the saving, at best, amounted to 2s. per ton on a product selling at anything between £10 and £50 per ton, and the record does not show how much expense was entailed in the adjustment of the steam supply to the pulping vats and the drying cylinders. In the textile, sugar-manufacturing, rubber, and confectionery industries, the problems are even more complex, and quite beyond the comprehension of the engineer who knows only power plant. Compared with the value of its output, the coal bill of a cotton mill is small, and, in addition to requiring power for driving the machinery, cotton manufacture demands steam for conditioning the atmosphere of the spinning rooms, for heating the yarn-dressing vats and dryers of the warpers in the weaving department, the kiers of the bleachers and the vats of the dyers, and other finishing operations.

Power plant is important in the different branches of wool manufacture for machinery drives, but it is also necessary as a steam producer for wool scouring and drying, for yarn dressing, felting and washing of woollen cloths, decatising and finishing of worsteds, bleaching and dyeing of all kinds of fabrics composed of wool. The steam-jacketed pans of the sugar manufacturer and the confectionery works, and the mixing rolls and calenders and vulcanising pans of rubber factories, are merely further items in a long list of appliances and processes that might be adduced to support Mr. Taylor's main contention that, while the central-station engineer may be safely left to deal with the problems of power generation, the industrial production engineer has to co-ordinate and subordinate the power plant to the manufacturing machinery and processes of commodity output.

Though evidently regarding the amount of the coal bill as a minor consideration in commodity manufacture, Mr. Taylor by no means condones boiler-house inefficiency, and pays a high tribute to the manufacturers who have improved the efficiency of steam-raising plants in recent years. Following up the con-

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Mr. William S. Murphy.

sequences of his main thesis, however, he advises that industrial engineers should demand consideration as a distinct branch of the engineering industry, and organise so as to co-ordinate the fruits of the experiences of each for the benefit of all. While agreeing that industrial production engineering should be regarded as a distinct and important branch of the industry, I consider that the formation of a new association would be a mistake. Not only are there too many engineering associations already in existence, but Mr. Taylor's laudable aim can be attained better by other means.

Manchester University provides instruction in cotton manufacture engineering; Leeds University has special courses for students of woollen and worsted machinery; Sheffield, Nottingham, and Birmingham Universities all afford facilities for the study of the equipment and plant needed for their local industries; and Glasgow University might undertake the teaching of industrial engineering on a wider basis. Prof. Cormack rightly claims that the university fulfils its function by teaching engineering students the fundamentals of their profession, and training them in methods of acquiring further knowledge from practical experience and reading, but it would be a valuable addition to their equipment if they were taught the main lines of industrial engineering, as practised in the manufacturing establishments of the country. Perhaps the suggestion that a chair of industrial production engineering should be established is premature, but, at any rate, Mr. Taylor's valuable paper merits some practical recognition.

Mr. James R. Edwards: I agree with Mr. Taylor that the value of the works engineer has not in the past, and is not now except in special cases, fully appreciated by the directors of manufacturing companies. One of the principal reasons for this is, I believe, that the industrial engineer does not very often come into close contact with the man who can put his ideas into operation, that is the managing director of the business. In many cases any important schemes are submitted to the works manager, who most likely has been trained to a

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Mr. James R. Edwards.

different profession from the engineer, and who may not be able to grasp fully the possibilities of the scheme, with the result that it might be dropped altogether or put forward in a manner approved by the works manager, but which might not be the best. The works manager can in most cases discuss important issues with the directorate more frequently than the engineer, and often puts forward the engineer's ideas, although he may have a very imperfect knowledge of the subject. This I do not think is right. Any engineer with a real knowledge of his business would make sure that his schemes were sound, and when fully satisfied on this point he should be in the position to put them before the directorate, and express his views directly.

I entirely agree with Mr. Taylor with regard to the use of electricity. In large factories or works where steam is used for process work or heating, full use should be made of back-pressure steam plant. In ideal circumstances, the electrical power would be generated in the firm's own plant to drive their machines, while the heating and process work would be done by the exhaust steam. Very great economies can be made even with old engines which have not been designed to work against back pressure. Most old engines are sufficiently robust to work against a back pressure of 10 lbs. per square inch, and the alteration of the valve gear to suit the altered conditions is, in most cases, not an expensive matter. In many engines I have indicated, the back pressure in the low-pressure piston was 10 lbs., even when the engine was exhausting to the atmosphere. This was due to badly-designed steam valves and small and tortuous exhaust pipes. In one case I remember, a compound pumping engine of 95 i.h.p. was using about 45 lbs. of steam per i.h.p. per hour when exhausting to the atmosphere, the exhaust steam being wasted, although there was a very large water-softening plant for boiler-feed purposes belonging to the same firm within one hundred yards of it. The back pressure due to the conditions mentioned above was about 10 lbs. per square inch.

By erecting a straight exhaust pipe of ample size from this

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Mr. James R. Edwards.

engine to suitable blowers in the heater tank of the softening plant, and altering the valves of the engine, the back pressure was reduced to 2 lbs. per square inch, the steam consumption fell to 27 lbs. per i.h.p. per hour, and the whole of the exhaust steam was used for feed-water heating. As the steam in this case cost about two shillings per 1,000 lbs. and the engine worked 168 hours a week, the saving due to the alteration was considerable. I quote this case to show what can be done by the steam engineer, because the firm had practically decided to electrify the well-pumping machinery, but when the change was made the electric drive did not have a look in. In many cases steam at 10 lbs. per square inch pressure is sufficient for evaporators and other process plant, or for factory heating.

I could mention scores of similar cases which I have come across from time to time, but the word electrical seems to have a strange fascination for some people, and plant is electrified when better results could have been obtained by combined power and heating steam-plants. I have found from experience that in many cases cheap electrical power does not necessarily mean low production costs, but it is difficult at times to convince people of this. In many cases the electrical plant is put in, and, the money being spent, continues at work, losing money for the owners, while the more suitable steam plant is not even afforded an opportunity to show what it can do. I hope, if the Engineers Bill, which is at present before Parliament, is passed, the status of the industrial engineer will improve. In most instances this member of the works staff can save more for his employer than any other person. He seldom gets even a "thank you," if his schemes, when put into operation, save money, but it is certain that he will get all the kicks if they do not.

Nowadays a great deal is heard of expert salesmanship. If a salesman doubles his sales he is usually well rewarded, but if an engineer reduces his working costs by half, he is more often than not ignored, and the credit due to him is filched by others.

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Mr. A. Kristian Bak.

Mr. A. KRISTIAN BAK: Mr. Taylor deserves great credit for bringing forward two things of importance to industry, namely, the need for the industrial engineer, and the value of "getting together." I believe that this appeal to get together has a call not only to industrial engineers, but to all engineers in industry. Consideration of the freedom and frequency with which engineers of competing firms in America meet and discuss their problems leads to the belief that that is one of the things which has helped to push the American industry into its leadership. The day of industrial secrets should be over, but, generally speaking, European manufacturers have not yet realised this. Why, even the power plants in Europe, which certainly contain no secret processes whatever, are not generally open to visiting engineers without a lot of introductions, red tape, and permits from here and there, and as for discussing operating experiences, in most cases it can hardly be called a discussion. A change for the better is noticeable in the last few years, probably because so many European engineers have been to America and seen the methods adopted there; may it continue to grow and spread to all branches of industry.

Mr. Taylor defines the industrial engineer as one who should have supervision of the design and operation of steam plants for the industry, and an audible voice in the organisation and conduct of all the processes that depend upon steam and power for their economical working. His problem, then, is a double one; firstly, the economical production of an adequate amount of steam and power—this also includes the design of the proper type of plant—and secondly, the economical use of this steam and power in the factory, considered from both a production and a heat point of view. The reason why the industrial engineer has not as yet obtained proper recognition and a place in industry is undoubtedly that manufacturers have so far considered only the first part of the problem, and have not realised the importance of the second part. Very often the cost of heat and power is only a small part of the manufacturer's total costs, and is, therefore, a saving of little interest.

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Mr. A. Kristian Birk.

Taking into account also the second part of the problem, the result may be not only a saving in the coal bill, but also an increase in production.

In my opinion, the industrial engineer should have not only an audible voice, but have a deciding voice in the economical use of steam and power in the factory. This calls for the best type of man, capable of making careful analyses and doing a great amount of development work. The first part of his problem—the economical production of steam and power—is identical with that of the central-station engineer, and the real difference between the two is that, while the central-station engineer is not concerned with the power after it leaves the plant, the job of the industrial engineer is only half done at that point. I would emphasise very strongly the difference between the two types of engineer, as it seems as if, in many cases, the best material for industrial engineers would be young engineers with some central-station training.

Mr. Taylor states that competition among manufacturers of equipment is largely responsible for progress in central-station design, and later remarks that the development of mechanical stokers for the past 20 years has been brought about by stoker manufacturers. I believe this calls for correction. It cannot be denied that America takes a leading position in the art of combustion and the making of stokers, and for the past ten years the European design of central stations has been influenced to a large extent by American practice and experience, but the American development in equipment has been caused just as much, if not more, by the demands of the central-station men as by competition. It is only necessary to study some of the American publications, notably those by the N.E.L.A., to realise this.

Mr. Taylor: I should like to express my keen appreciation of the full discussion that has been generously accorded my paper, and I am very grateful to all who have added to its value by contributing to the discussion. As the discussion has reached a considerable length, I shall reply to the general

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Mr. Alfred J. T. Taylor.

points of interest that have been brought out, without mentioning specifically those who have been kind enough to emphasise these ideas. The principal points in my paper which have attracted attention seem to be:—

a. The title of the paper.
b. Is there a shortage of industrial engineers, and if so, who or what is to blame?
c. Why does Sweden make certain goods better and cheaper than we do?
d. Is it possible or desirable for competing sales engineers to meet in joint conference with their prospective client?
e. Is the free distribution of waste heat or power between adjacent industrial plants desirable or possible?

a. The title of my paper is not perfect. I have tried most of the other titles kindly suggested, and none seems to fit as well as the one selected. The title of "efficiency engineer" has to be abandoned at once, for the reason that unfortunately the term "efficiency" has fallen into disrepute. The term "production engineer" already has a definite limited meaning, and refers to a man whose specific function it is to see that the goods are produced as and when required. As an alternative title, I am inclined to that of "executive engineer." I think it perhaps more nearly describes the functions that I am hoping will ultimately be delegated to industrial engineers.

b. I totally disagree with those who say that the supply of industrial engineers is either adequate or competent. The number of really well-equipped industrial engineers of this country—and we are not unique in this—is very limited. The whole burden of my paper is that we need industrial engineers; we have the means to develop them, but we have neglected their development. There was no intention of slighting or ignoring the consulting industrial engineer. We need them all, and it is quite immaterial to my object whether the industrial engineer serves one or many masters—whether he is

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Mr. Alfred J. T. Taylor.

a whole-time employee of one company or is a consulting engineer serving several firms.

c. What I thought was one of the most striking points in the paper was the reference to an industrial firm in Sweden, but it was mentioned by only one contributor to the discussion. The explanation of the lower cost of production in many lines in Sweden is found, I think, in the greater goodwill among the workmen. They do more work per hour, and in some cases the factories themselves are much better equipped and conducted. But goodwill towards the business is, in my opinion, the chief reason for lower costs.

d. I do not agree that round-table conferences between competing sales engineers would either limit competition or delay business. I feel that they would promote frank discussions of equipment on its merits. Sales engineers would be developed who could clearly express their ideas. Unkind and generally untrue statements about competitors' goods or competitors themselves would cease to be used by sales engineers, and the client with a judicial turn of mind would be able to judge between the merits of one piece of equipment and those of another on a much sounder basis than is possible at present. Such conferences do take place now in the sale of certain equipment, as I can relate from personal experience.

In Canada, some years ago, I persuaded certain prospective clients who were in the market for centrifugal pumps to call together at one time all the salesmen of the various makes of pumps that were under consideration, and to request each of them to discuss their particular pump, its design and efficiency, and other points of merit, in the presence of the client and the assembled salesmen. The discussion of price was not included in these conferences, and, indeed, it was not my intention that it should be. These conferences developed the fact that some sales engineers did not thoroughly know the article they were selling. Their knowledge of their competitors' article was generally limited to its weak points, which were often emphasised out of all proportion to the facts. The effect of these conferences was almost instantaneously to raise the

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Mr. Alfred J. T. Taylor.
standard of the sales engineer, and enable the client to decide whether he would have higher efficiency and performance at an increased price, or whether he would be satisfied by lower efficiency at a lower price.

There is another advantage of joint sales conferences. Things move quickly to-day, and time is valuable. It is as unjust for an incompetent sales engineer to waste a client's time as it is for the client to waste the sales engineer's time, either by not knowing what his problem is, or through being insincere in his expressed intention to buy equipment on its merits. I am referring particularly now to the case of a buyer who has already made up his mind to give his order to a certain firm, but nevertheless puts a number of firms to the expense and trouble of competing for this order, which they have no possibility of getting. This condition would soon be apparent if competing sales engineers met together.

e. As to the free distribution of surplus heat and power between adjacent plants, I am genuinely disturbed to learn that restrictive legislation has already appeared in this country. It is a standing reproach to industry that this should be so. Why talk of national economy and then restrict one of the most definite and fruitful channels to this end? There is the equivalent of hundreds of thousands of tons of coal being dissipated as waste heat throughout the country, much of which heat could be economically harnessed to produce power for the benefit of industries. In some instances, this heat could be with great advantage used in the production of fruit, flowers, and vegetables under glass. Last year there was a scheme on foot to erect extensive glass houses for growing vegetables in Iceland, these glass houses to be heated by the hot water that is natural in some parts of that country. That scheme rested on sound commercial grounds, and will probably go forward. Why should we not do exactly the same thing with some of the waste heat in this country? It is being dissipated in surprisingly large quantities, and I am perfectly certain that there are cases where it could be economically used.

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Mr. Alfred J. T. Taylor.

In Germany during the war an exhaustive survey was made of all industrial plants, and those having waste heat were paid to harness it and supply it either to adjacent plants or through central electrical distribution channels. This good work still continues in many parts of Europe. No one, however, will undertake the utilisation of waste heat and the conversion of it into some useful form if troublesome restrictive legislation stands in the way. It is perfectly absurd to think that the owner of a private industrial plant with a surplus of either heat or power should not be free to dispose of it to his neighbour if he wishes, provided, of course, that he conforms to the ordinary regulations designed to protect the public safety. The industrial engineers of this country should safeguard our industries in these matters, and not let the more active central-station engineers have things all their own way.

In concluding what I feel is an inadequate reply to many of the points that have been raised, may I again express the wish that those who are engineers in industry will realise the responsibility that rests upon them to play to the best of their ability an active part in raising the status of what I have termed the "industrial engineer," and in so doing contribute to the stability and development of the numerous industries upon which the future prosperity of Great Britain depends.

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BRITISH ENGINEERING EXPORT PROBLEMS.

By William S. Murphy.

18th October, 1927.

Introduction.

For some time past anxiety has been expressed regarding the ability and willingness of British engineers and shipbuilders to compete with their rivals in other nations in salesmanship. This paper has been written to present a temperate and reasoned view of the British engineers' marketing problems, taking into account the distaste of the men who have built up the metal manufacturing, marine engineering, shipbuilding, and power engineering industries of Great Britain for talk that does not help work and all forms of boasting. By collating the opinions of British observers in foreign markets, an attempt has been made to show that the progressive development of salesmanship in British engineering export is desirable.

Retrospective.

Experience helps to shape the practical judgments of men, and the history of British engineers and shipbuilders in international trade should indicate the causes which moulded their business policy in the past, and the course of action they may be expected to take at the present juncture. British iron and steel manufacture, marine engineering, shipbuilding, railway engineering, and the production of power plant and power-driven machinery originated in individual enterprise, and created around them a privacy through which the organs of public opinion seldom penetrated. Even in their commercial

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transactions, the early engineers had little contact with the general mass of mankind, to the vast majority of whom the building of great steamships, the making of locomotives and steam engines, the casting of iron and the forging of steel, were mysterious and wonderful operations. Contracts for work were arranged between shipowners and shipbuilders, between directors or managers of railway companies and the firms producing rails, locomotives, and rolling stock, between the owners of industrial works, mills, and factories, and the engineers manufacturing power plants and machinery. Each transaction was conducted on ordinary commercial principles as the private business of the parties concerned, and it mattered little, as a rule, whether the buyer and seller were next-door neighbours or separated by ocean spaces. While producing supply of home needs for engines, pumps, boilers, machinery, ships, marine engines, and railway equipment, British engineers acquired a skill and facility of production which brought buyers from most of the civilised countries on the face of the globe, and the export trade of all branches of the industry grew rapidly. British steam plants and machinery, rails and locomotives, were imported by France, Germany, Spain, Portugal, and other European nations, and the demands from across the Atlantic were numerous and insistent, Great Britain figuring in the minds of men as the supreme "workshop of the world" for a time.

But, though pre-eminent in many branches, Great Britain never was the only country in which metal manufacture and engineering were practised, and within a short period those nations which possessed coal, iron ores, and mechanical aptitudes began to aim at self-subsistence in regard to railway construction and equipment, power plant and machinery, each framing its fiscal policy so as to restrict imports and afford the utmost possible protection for its own iron and steel and engineering industries. The needs of the world for ships and machinery of all kinds continued to expand and grow, however, and history shows that shipbuilding and engineering, though encountering foreign competition, suffered less than

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any other of the great exporting industries from the fluctuations that alternately depressed and quickened British trade all through the nineteenth century. But the causes of severe trial were being formed. During the early 'seventies of the last century, the iron and steel manufacturers and engineers of the United States persuaded their Government to adopt a high tariff policy so as to exclude foreign competition from the American market, and Germany, having acquired the coal mines, iron mines, and engineering works of Alsace-Lorraine, began to strive for a leading place in the engineering world. Though the double blow affected it seriously for a year or two, the export trade of Great Britain was not permanently injured by the changed conditions, for her engineers had already found in railway and other enterprises in South America, India, Australia, New Zealand, and elsewhere, more than ample compensations, and her shipyards continued to supply the bulk of the shipping needs of the world's commerce.

But gradually the iron and steel manufacturers and engineers of Europe and America passed from supply of their own local needs to active competition in the markets of every country In railway engineering and equipment, in machine-tool manufacture and electrical work, the energetic industrialists of the United States cultivated an export trade with great assiduity. Backed by Government subsidies, the German shipbuilders gained for a time the "blue riband of the Atlantic, and the armament firms, locomotive builders, iron and steel makers, and power plant and machinery producers of that country were making headway in all lands, even in the home market of Great Britain itself. Year by year the intensity of international competition increased, France, Belgium, Italy, Switzerland, Holland, and Sweden all striving to increase their shares in the supply of the world's iron and steel, railway, transport, and engineering needs. From press and platform warning voices were raised, calling the attention of British engineers, in all branches of the industry, to the growing strength of their foreign competitors, but they were not greatly perturbed, calmly assured of the growing capacity of civilisation to absorb

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all the products of the combined industries of all the nations. To a degree not now ascertainable, the confidence of the British engineers and shipbuilders was justified. At any rate, the period which was abruptly closed in August, 1914, had been a fairly prosperous time for them. Markets were shrinking here and there; competitors were encroaching on the British home market for machine tools, for tubes, for electrical and various supplies; a few large contracts in certain British Dominions had been lost to foreign firms; but these happenings made a light impression, for there was little unemployment in any of the important branches of British engineering, and business was fairly profitable.

The Force of Public Opinion.

Ever since they became of national importance, the British engineering industries have been subjected to a constant stream of adverse criticism, derogatory comparisons, and forecasts of bankruptcy. As far back as 1843 Thomas Carlyle scoffed at Great Britain's "loss of prestige in the Councils of Europe," then supposed to be agitating the public mind, but lamented that, according to the reliable testimony of a German friend, the high European reputation of British cutlery and small tools for soundness of material and quality of workmanship had seriously declined. Sheffield cutlers, perhaps profiting a little by the admonition, have continued to enhance their reputation and increase their export trade. Though the prophets have often been led astray through lack of knowledge, it would be foolish to argue that the industries of Great Britain have not derived progressive stimulus from that impalpable and strangely potent influence commonly denoted as the "force of enlightened public opinion." Engaged in an industry which demands the closest attention to practical details, but which is so widely spread through numerous branches, so prolific in development, so deeply interwoven with the fibre of civilisation as to be affected by political, financial, and commercial influences of all forms and degrees, the engineer needs a com-

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prehensive vision and adaptability beyond human powers unaided by the social consciousness created and sustained by the interchange of opinion. Though the branches of the industries most concerned possessed within themselves adequate powers of self-evolution, there can be no doubt that the development of the water-tube boiler, the internal-combustion engine, the steam turbine, the motor-driven ship, and the motor car owes a great deal to intelligent criticism and to the comparisons set up between the progress made by one nation and another. Standardisation of materials and machine parts, mass production, and metallurgical and mechanical research in Great Britain have been aided largely by intelligent criticism. It must be admitted that the right of the general public to an opinion upon their business has not always been conceded by all the branches of the engineering industries. Near the close of the last century, British machine-tool manufacturers, secure in an unrivalled reputation among the firms that were of consequence, refrained from publicity, and allowed the younger generation of engineers and ship-builders to grow up in ignorance of their existence. American and German machine-tool makers invaded the undefended British market, and attained a success that must have astonished themselves. With characteristic sagacity, the British public protested against a state of affairs that imperilled the national safety, but the machine-tool makers manifested a proud indifference for a while, and only began to bestir themselves in time to be ready for the emergencies of war. Awakened to the folly of aristocratic pretence in a practical industry, and stimulated by the demands of the great conflict, the machine-tool makers of Great Britain revived their latent powers, returned to the market, and resumed their supremacy. Quite different have been the relations of the British marine engineering and shipbuilding industries and the general public. In the month of March, 1925, Lord Furness, the chairman of Furness, Withy & Co., Ltd., announced that his firm had placed an order for five motor-driven ships with a German shipbuilding company, because their offer

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was £60,000 less than that of any British firm. Startled and indignant, the British public demanded explanations Although quite well aware that the German shipbuilders could not fulfil the terms of the contract except at great loss, the Shipbuilding Employers' Federation invited the trades unions engaged in shipbuilding and repairing to set up, in co-operation with them, a joint committee to "investigate conditions prejudicially bearing on the shipbuilding and ship-repairing industry in connection with foreign competition," and to publish a report. After long and careful investigation, the joint committee arrived at a number of definite conclusions, of which the following is a fair summary:—

"During the proceedings of the joint committee, the Employers' representatives pointed out that the margin of difference between the British and German prices in the case of the Furness-Withy contracts was quite abnormal, and did not represent accurately the general run of the margin between British and foreign tenders. The shipbuilders' representatives explained that in many contracts for new work, particularly for the bigger ships which gave the greatest amount of employment, and the majority of contracts for repair work, in which Continental competition, particularly of Rotterdam firms, was most keenly felt, the margin of difference was not so great. In these cases, by minor readjustments in handling and greater elasticity in the organisation of work, by interchangeability, and by the loyal and full observance of the conditions of the 47-hour week, much of the new work and the greater portion of ship-repairing work, which at present goes to the Continent, could be retained for the British workmen and the British shipbuilders. This would also, the shipbuilders hoped, encourage owners to place work at the reduced prices, which would thus be secured without interfering with the wages or increasing the working hours of the shipyard workmen."

Taken as a whole, the "Report of the Joint Committee" supplies evidence of the practical sagacity with which the marine engineering and shipbuilding branches of the British

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engineering industry utilise public criticisms for the furtherance of economy and efficiency, while, at the same time, allaying the legitimate doubts and fears of the nation.

Dealing with a Changed World.

During the four years between August, 1914, and November, 1918, the industrial energies of Great Britain were absorbed mainly in supplying the allied armies with munitions and equipment, and orders for plant and machinery from countries outside the war areas were rarely accepted and still less often executed by British producers. The engineering industries of the United States, so long as it was neutral, of Switzerland, Holland, Spain, Sweden, and Denmark had a period of great prosperity, limited, of course, by the high prices of metals and raw materials, and the costs and risks of transport. Because supply of their engineering needs was costly and inadequate, the non-combatant countries in Central America, South America, and elsewhere sought remedy in restriction of requirements and temporary substitutes. When the dark pall of war lifted, it revealed a changed world, and the nature and depth of the changes were appreciated by no one.

At the time of the armistice all the industrial forces of the nations prepared to enter upon an era of splendid activity, but unexpected gulfs and chasms appeared on their lines of march. Unproductive expenditure and destruction of materials and purchasing power on a scale surpassing the productiveness of industry over 50 years, had impoverished the world. The foundations of exchange had fallen away, and buyers and sellers stood helpless on either side of the chasm. Gradually settlement, though of a makeshift kind, has been attained, and it is possible for the British engineer to take a rough survey of the markets. Born in a free-trade country, the British industrialist is first struck by the extraordinary growth of protection in all the other countries of the world. Fiercely nationalist, the young nations created by the peace treaties have set up high tariff barriers to safeguard their industries and obtain revenues

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for self-defence. Poland, Jugo-Slovakia, Czecho-Slovakia, Lithuania, Esthonia, and Hungary have imposed high import duties on most engineering products; Spain has framed a fiscal policy to exclude foreign engineers from her territory as far as may be possible, and to foster metal manufacture and engineering on her own soil; France aims at complete self-subsistence; and Germany has erected a high tariff wall, linked together her metal manufacturing and engineering firms by cartels and agreements, so that the domestic supply is safe-guarded, and developed a strong export organisation. On the other side of the Atlantic, the United States engineering interests of all kinds are defended by high import duties from foreign competition. In most of the South American countries native-born authorities have largely displaced alien agents and shippers, and efforts have been made, by Government regulation and legislative enactment, to reduce the proportion of foreign owners and directors of industrial enterprises. Realising that they have been exploited by foreign investors and contractors, the Brazilians, Peruvians, Chileans, and the citizens of Argentina endeavour to practise policies by which the mines, railways, and industrial works shall be of greater advantage to them and less profitable to the foreigner. Consequently, capital for railway construction and rolling stock, and for plant and machinery needed by industrial establishments, is difficult to raise. Throughout the whole of South America commerce and industry grow rapidly, but the depots and works are mostly in the hands of new firms. Therefore, although British engineers, constructors, and railway engineers still retain some hold on the markets of Brazil, Peru, Chile, Bolivia, Argentina, Paraguay, Uruguay, and Colombia, they are confronted with the need of building up new connections in many places.

Apart from foreign competition, which must be dealt with separately, the most perplexing problems of the British engineers are connected with the engineering establishments which the Dominions of India, Australia, New Zealand, and South Africa have inherited as a legacy from the Great War.

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Before 1914, India possessed an engineering industry of considerable importance. It originated chiefly from the railway depots, the workshops for railway repairs and supplies, and the mechanics' shops associated with cotton and jute mills, mostly in the localities of Bombay and Calcutta. India, however, needs pumps, flour mills, plantation equipment of various kinds, and numerous other power-driven machines, and small works established in the vicinity of railways or mills were called upon to supply local needs. To trace the growth of engineering in India, even in outline, would take us too far out of our way, and the fact of the greatness of the industry must be accepted. When the Great War came, India was thrown back upon her own engineering resources, and she undertook the burden willingly, developing works with great rapidity. In 1918 the iron and steel manufacturers and engineers in India demanded protection and further employment, and claimed that Indian railway and Government supplies should be locally obtained. Reinforced by native nationalist sentiment, the movement gained force, and now all Indian Government contracts are framed for rupee tender and open to all the world. British engineers are consequently faced not only by native Indian competition, but also by the competition of Germany and America. Somewhat different are the cases of Australia, New Zealand, and South Africa. Australia seeks to foster the metal manufacturing, shipbuilding, and engineering works that have grown up on her soil, by means of import duties and other aids, but Australians endeavour to restrict foreign competition with the Mother Country. A preference, such as it is, is afforded British engineering products, but a market which, in years not long gone by, was an outlet for free British enterprise has become restricted and difficult. In New Zealand a similar position has arisen, and British engineers encounter import duties where formerly were free ports. South Africa has moved a step farther. Import duties are imposed on iron and steel, plant and machinery, without any form of discrimination or preference. Perhaps, in this brief and, therefore, bare outline

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of the present international position, it may seem that there is a slight suggestion of general hostility to the British engineer, but the facts do not bear that interpretation. Each state is pursuing its own interests, protecting its producers so that they may survive competition, reaping what revenue it can from imports, and seeking wealth from the exports of its surplus commodities. For British statesmen and the iron and steel manufacturers, shipbuilders, and engineers of Great Britain, the situation is more complex, and the lines of industrial and national policy more difficult to define.

Advices from Overseas.

Some publicists assume that the sole factor in the problem of engineering export is the competition of foreign rivals, and that once the quality and amount of that opposition has been ascertained the way is opened to a solution. But it may happen that some of the difficulties arise from the methods of British engineers themselves, and the testimony of those who are witnesses of the overseas import of engineering products should serve to throw helpful light on the matter. Moreover, views of competition in distant markets taken from the British Isles alone may be partial and somewhat lacking in perspective, and the importance of the question demands the most accurate knowledge possible. Representatives of British industry and commerce have organised associations of various types in nearly every important business centre on the face of the globe. Members of British Chambers of Trade or Commerce, in Rio de Janeiro, Sao Paulo, Santos, Madrid, Barcelona, Bilbao, Calcutta, Bombay, Madras, Perak, Selangor, Hong Kong, Shanghai, or elsewhere, are residents of the city or province to which the association belongs, and live in close personal touch with the native community, speaking the language of the country, and sharing the interests of the inhabitants.

Engineering interests are frequently strongly represented in those organisations, and their periodical reports often contain

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information of great service to the engineering firms of Great Britain. Occasionally the advices from the executive officers of British Chambers of Commerce in foreign lands are direct and particular. For example, the secretary of such a body in a Chinese city may call the attention of British engineers to the injurious reports sent to China by British news agencies regarding the efficiency of some branch of engineering, the items deriving their sole news value from the fact that they are harmful to British industry. Or, more happily, the executive of a similar body in South America may advise engineers in the homeland of impending railway schemes, of changed financial and commercial conditions, or competitive activities displayed by engineers of rival nations, and so on. Moreover, there is the important fact, which some overseas critics and newspaper writers too often forget, that numbers of British engineering and shipbuilding firms have agents, depots, and even branch works, in lands overseas, whence they receive business information constantly. But it is quite clearly evident that the knowledge derived from all these sources is not sufficiently diffused. A recent addition to the sources of information at the command of every British engineering and shipbuilding firm is the series of booklets issued at short intervals by the Department of Overseas Trade, containing reports of consuls, commercial secretaries, or other representatives of British interests, on the industrial, financial, and commercial conditions of the countries in which they are stationed. From these reports, it would be possible to compile a valuable guide to all the engineering markets of the world, but as the present discussion relates to marketing problems, only those passages bearing on that subject should be quoted.

Writing from Mexico City, Mr. Norman King explained the situation for British manufacturers in Mexico, in the following terms:—

"The chief asset of the British manufacturer in this market is the reputation which he enjoys for the quality of his goods. During the period immediately after the war, numerous appli-

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cations were received in this office from importers who wished to renew their former connections with British firms. Equally numerous complaints were then received regarding the high and fluctuating prices of British goods and the uncertainty of delivery. . . . If business is to be done on a scale of any importance, it is essential to send out efficient commercial travellers. In this respect, the British are said to lag still a good way behind their American and German competitors. . . . Competing firms must be prepared to advertise when conducting a sales campaign. The system of advertising by posters, on hoardings, electric signs, etc., has made considerable advance in recent years, and it is noticeable that most of the advertisements are American, and very few British."

Though these remarks apparently relate chiefly to general merchandise, the Consul-General indicates that a firm whose name is known in Mexico through popular advertising has a better chance of obtaining even large engineering contracts than one depending simply on the value offered.

In his report on Venezuela, Mr. H. A. Hobson, H.M. Consul at Caracas, stated that:—

"Advertising is mostly through the medium of newspapers, but is of great importance, and if possible agents should be granted an allowance towards their expenses in this respect."

Pointing out that there are openings for British firms in agricultural, textile, road-making, and oilfield machinery, gas and oil engines, light railway material, and wire ropes, Mr. Hobson added:—

"Catalogues, propaganda, etc., should always be in the Spanish language, correctly rendered; measurements and weights in the metric system, and prices in the currency of the country, if possible."

In his most recent suggestions for British exporters, Mr. William C. Graham, stationed at Ecuador, also touched on the language question:—

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"The attention of British firms is again drawn to the all-important question of having their catalogues published in the Spanish language for distribution in South American countries."

But he also called attention to occurrences in Ecuador which are of interest to British engineers, thus:—

"There is also a growing market for industrial and agricultural machinery, and German and American manufacturers have already established engineering departments in this country, carrying various kinds of machinery in stock, which place them in a favourable position to obtain contracts for the supply of any such material."

Mr. J. P. Trant, H.M. Consul at Callao, in a recent report on Peru, pointed out that there is a constant demand in that country for agricultural, ginning, textile, electrical, and other machinery, and iron and steel products of many kinds, but indicated that the British share of the business was not so large as it should be, and contrasted the efficient salesmanship of American firms with the comparative slackness of British engineers. Repeating a lesson he had tried to enforce in previous reports, Mr. Trant said:—

"No harm can be done by reminding British manufacturers once again that Peru is a Spanish-speaking country, and that consequently all their business transactions with Peru should be governed accordingly, both in respect to correspondence by mail and in the selection of travellers, or representatives, thoroughly conversant with the language and of good address and education. The past year has witnessed the presence in Peru of a very high percentage of travellers without knowledge of the language or of the customs and history of the country."

Still more drastically critical was Mr. W. F. Vaughan Scott, of Santiago, in his report on Chile, dated September, 1924. Mr. Vaughan Scott set forth his complaints and criticisms in a series of propositions, thus:—

"1. The difficulty of obtaining reliable information concerning British manufacturers generally.

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2. Whilst a large number of American catalogues are regularly circulated, British catalogues are rarely received.

3. British catalogues, more often than not, are in English, which is Greek to the Chilean, and when translated into Spanish are frequently full of mistakes; they contain English weights and measures; they are not illustrated or sufficiently explanatory.

4. British representatives are not sent out often enough, and those who do come (a) can rarely speak Spanish; (b) have to make a hurried trip lasting about a quarter of the time necessary; (c) only visit Santiago and Valparaiso, whereas they should make a prolonged tour of all the principal towns; (d) are sometimes not of a sufficiently refined type to be *personae gratae;* (e) rarely understand the mentality of the Latin races, among whom the Chileans hold a high position.

5. British technical magazines and reviews are not systematically distributed, nor are they made sufficiently attractive to create enthusiasm amongst the would-be Chilean readers and buyers. Similar American publications are regularly circulated amongst users of machinery, mines, industrial companies, clubs, etc. These publications are frequently supplied free of charge for a period of six months or longer, contain serial articles on technical subjects of sufficient interest to induce readers to become subscribers. Clubs are supplied free.

6. Amongst industrialists and users of machinery, complaints are general that agencies for the sale of machinery are given to firms who have no engineer qualified to advise them as to the types of machinery they should purchase."

Representatives of Great Britain in lands overseas refer frequently to the strict financial conditions imposed by British firms on buyers, and compare the credit facilities afforded by American and German firms with the terms offered by engineers at home. In his "Report on the Economic and Financial Conditions in Brazil," dated September, 1924, Mr. Ernest Hambloch, secretary of H.M. Embassy at Rio de Janeiro, discussed the question of credits, and stated that "Local

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agents and importers of British goods are unanimous in thinking that more business could be done from Great Britain if credit facilities were greater, especially with regard to railway rolling stock and supplies." It is to be feared that Brazil is in bad odour with British engineers with respect to the last-named commodities, but that matter may be left aside for the moment. Mr. Hambloch added:—

"A large proportion of trade from Great Britain to Brazil is done on reasonable terms of credit, but conditions in Brazil to-day are such that business from home could probably be considerably extended on reasonably sound lines by close and sympathetic examination of many cases where special credit facilities are requested."

Mr. Hambloch also reported complaints in Brazil that the supplies of catalogues by British engineering firms were wholly inadequate, and that too few were printed in Portuguese, the language everywhere used in Brazil. American and German engineering firms, he pointed out, advertised largely in the Brazilian press, and offered to advise any British firms undertaking advertising campaigns.

"British trade with the Argentine rests on solid and secure foundations," wrote Mr. H. O. Chalkley, C.B.E., in 1924, and his latest report, just published, from Buenos Aires confirms the statement. He has observed, however, several defects in British methods of trading with the great South American Republic. Makers of agricultural machinery in Great Britain do not appear to adjust the types of ploughs, tractors, threshing machines, and reapers and binders to Argentine conditions with the same facility as American firms, nor do they advertise so effectively. Government purchasing departments, he added, now entrust local agents with negotiations of contracts of considerable magnitude, instead of dealing with engineering firms direct, and British firms have failed to allow sufficiently for the change.

South America offers a vast and growing market for engineering products and activities of all kinds, and British engineers

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rightly strive for a large share in the supplies required, but Europe's demands are far greater, and afford larger scope for British engineering export. Protective tariffs notwithstanding, every country in Europe imports large supplies of engineering products, each country framing its fiscal system in the interests of its citizens. Great Britain everywhere enjoys "most favoured nation" treatment, and the sentiment of several nations is decidedly friendly, but the response of British engineers and manufacturers has been slow. Captain U. de B. Charles, commercial secretary to H.M. Embassy at Madrid, in his report of 1925, said:—

"The difficulty of introducing British goods into the Spanish market is not caused so much by lack of demand, even making allowances for the reduced purchasing power of the country and the high cost of production, as by a general unwillingness to meet the requirements of purchasers. It may be that British taxation is so high that it is difficult for some manufacturers to give the necessary credit abroad, or it may be the traditional conservatism which makes them prefer a small turnover and a high rate of profit in a known market. But, whatever be the cause, British trade continues to suffer from its failure to meet the requirements of the Spanish market."

Captain Charles also complained that many British firms neglected trade inquiries from Spain because they were written in Spanish, and sent too few qualified representatives to that country. On the other hand, Germany gave evidence of having resumed her policy of "peaceful penetration" in Spain, her efforts then being specially directed to establishing close business relations with Spanish shipbuilding and mining groups.

Reporting on British trade with Poland, Mr. R. E. Kimens stated that the difficulties encountered arose chiefly from the conservatism of the trading community in England, the higher prices of British goods, and the lack of confidence in the Polish market. He continued: —

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"British merchants continue to ignore the local requirements, and do not adapt their goods to the taste of the people; prices are not quoted f.o.b. Danzig; in the catalogues sent out to foreign buyers, the prices are given in sterling and the measures in English standards; tenders are seldom made in French or German, which are more accessible to the average business man in Poland than English; and firms in the United Kingdom continue to employ German houses as intermediaries, which is strongly resented by the Poles."

From every country in Eastern Europe come the same complaints of the slackness of British salesmanship, while the activities of United States automobile manufacturers in establishing service systems, showrooms, and canvassing forces, and the constant propaganda of the German engineers, are reported as everywhere evident.

European and British engineering affairs will probably adjust themselves in ways that cannot at present be forecast, but a survey of the requirements of the British Dominions and Crown Colonies, and the marketing problems they present, may be of practical use. Reporting on the "Economic and Financial Conditions in the British West Indies," Mr. J. Wilson Goode spoke of American and German competition in these terms:—

"It is true that, in many important lines, the United Kingdom has since (the war) recaptured its trade, but the predominance of American productions over a period of several years has left an enduring mark upon the trade of the British West Indies. In point of quality there is a decided preference for British goods, but extensive advertising by American firms causes articles to become more widely known, and although there are no more loyal subjects than the people of the British West Indies, after all the aim and object of a supplier is to provide his customers with what they want, and not what is considered good for them. . . . Until recently, German efforts to secure trade were confined to the wide distribution of up-to-date catalogues and other literature, and to the appointment of local agents. Now, however, German travellers

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are commencing to canvass these markets, and it is probable that German activities in this direction will increase."

Australia and New Zealand are in the throes of industrial and commercial development, and, though they tend to a closer affinity with South Africa, Canada, and the United States than with Great Britain in respect to social, commercial, and industrial development, these great markets may be kept open for British engineers and shipbuilders by mutual frankness designed to establish an understanding on the basis of common interests. The New Zealand Government has noted with regret that, in the report of the Census and Statistics Office, "The most outstanding features brought out in the tables of imports are the growth of trade with the United States and Canada, and the decline in the Mother Country's share of goods entering the Dominion." It must be admitted, moreover, that up till a quite recent date the marketing problems presented by Australia and New Zealand had not been resolutely tackled by British metal manufacturers, engineers, and shipbuilders, and the same must be said of India and South Africa; but it is necessary to note that in all those countries German and American firms are pursuing a policy of intensive propaganda.

In his "Report on Canada as a Market for British Goods," Mr. F. W. Field, H.M. Senior Trade Commissioner in Canada and Newfoundland, has noted a misleading assumption held by many people regarding the markets in all parts of the British Empire. He said:—

"Certain British firms are inclined to take for granted that Canadian consumers have a knowledge of their products just as the buying public at home. They conclude that because Canada is a part of the British Empire its knowledge of British products is extensive, even although those products have not been advertised or sold previously in the Dominion."

Mr. Field refers specifically to goods sold retail, but the principle applies to plant and machinery as well. The supreme

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excellence of British engineering products is known wherever the English language is spoken, but a manufacturer in New Zealand, Australia, South Africa, or Canada cannot be certain that any firm in Great Britain is able and willing to supply precisely the kind of plant or machinery he needs.

The Marketing of Engineering Products.

Iron and steel manufacturers, marine engineers, shipbuilders, makers of plant and machinery, and engineers generally in Great Britain have been difficult to persuade that they make things to sell. Accustomed to contracting to produce a given ship, or engine, or machine, or taking orders for those commodities and supplying them, at an agreed price, for more than a century, they reluctantly enter the markets where competing vendors are striving to persuade buyers to purchase their products. Selling organisations are comparatively new to the engineering industries, but now they have grown to be a necessity. According to his expert advisers, the British engineer engaged in export must organise a publicity department, which would compose and issue a "house" organ, concoct news bulletins for the press or news agencies, prepare advertisements, compile catalogues and translate them into as many languages as there are nations to whom they may be addressed, arrange for special articles to be published in foreign and colonial newspapers and periodicals, and periodically launch publicity campaigns in various districts or countries. Next, there is the canvassing or travellers' department, whence trained engineers and linguists would be sent forth on missions of order-collecting from manufacturers, mining engineers, railway authorities, government officials, and everyone having the power to buy plant, machinery, locomotives, rolling stock, electrical machinery, or any other product made in the works. Meanwhile the heads of the firm would be busily employed in engaging agents, organising and equipping agencies, or probably setting out on visits to possible customers in distant lands, where they might be called upon to set up supply or

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service depots. Formerly it was the exclusive function of those engaged in the engineering industries to produce, but now, if the advices so urgently offered are acted upon, the greater part of the time of a large special staff would be taken up in the work of marketing. Highly coloured though the picture may appear to those outside the modern movement, it is modest compared with the reality.

Competitive publicity, in the present day, knows no bounds At regular intervals numerous firms in Great Britain receive a periodical from Germany, well written in English, finely illustrated and clearly printed, describing German engineering products of various kinds, the journal being circulated in all English-speaking countries. It is translated into Portuguese for Brazil, and into Spanish for the rest of South America. Though German engineering catalogues are translated into various languages and widely distributed, they are not so effective as the special articles supplied free to nearly every important periodical in the civilised world. German publicity is intensive, and finds its way, partly by advertisement and partly by lavish supplies of news paragraphs, into the local newspapers of Brazil, Peru, Mexico, Chile, the Argentine, and nearly all the British Dominions. American publicity takes a stronger course. Several important South American and Far Eastern journals are owned by United States engineering and automobile manufacturing firms, who use them for propaganda. The American engineering technical press is the most powerful in the world, and while the greater journals are only supplied to subscribers, the lesser periodicals, generally owned by the same publishers, are distributed free in every civilised country. Advertising campaigns are a regular feature of American engineering business, ranging in scope and form from a flood of finely printed and illustrated catalogues to a mission armed with paste pots, brushes, and posters, sent on a round of two thousand miles. Reckless though it appears, the publicity of the United States is planned with meticulous care, the capacity of every region to absorb the commodities to be offered, and the publicity value

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of every newspaper or local journal, having been estimated beforehand.

To any impartial reader of discourse upon the engineering market of the world, it may seem that the writers have become obsessed with the idea of denouncing German and American competition, for the names of the two nations constantly recur. But the fact is inescapable. For example, while French, Belgian, Dutch, Swiss, and Italian engineering firms employ travellers, who are to be met with in nearly every important commercial and industrial centre, the number of German travellers and the swiftness and ubiquity of the "drummers" from the United States attract the attention of foreign observers. German travellers infest countries so sparsely populated as Angola and lands so poor as Finland, their proportion in the latter country to British travellers being about eight to one. In South American countries the American and German travellers are said to compare favourably in ability and equipment with the average British representative, and they are more numerous.

Comparisons are liable to misrepresentation, but correspondents in some foreign countries more than hint that the agents of British engineering firms are less liberally treated than German and American agents. In some cases, the terms quoted are lavish according to British standards. On the other hand, the manner in which the agents of British firms in foreign countries are selected is the subject of censorious criticism by our overseas representatives.

Frequently British foreign correspondents invite the engineering firms of Great Britain to rival the showrooms and depots established by German and American firms in certain cities, with respect to display and equipment; but as the American showrooms are chiefly connected with the motor-car trade, and those of the Germans devoted mainly to small tools and hardware, British engineering firms dealing in plant and machinery need not to be greatly tempted by the invitation.

In the present impoverished state of the world, the British

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habit of collecting debts when they are due and restricting doubtful credits may affect them adversely in some markets for engineering products, but the practice is salutary. United States firms, however, have introduced the hire-purchase system into lines of business in which it is unusual, and probably the innovation may be of service to both buyer and seller.

To explicate the subject farther is needless. It is abundantly plain that the engineering exporters of the world outside Great Britain have decided that selling is a function almost equal in importance to production, and there is a probability that they may be right, for the moment, at least. At the present time, the productive powers of the engineering industries are far in excess of the existing demand, and if the stimulation of the absorbing capacity of the market brings the demand nearer to a level with production, the vast expenditure involved may be more than repaid.

The Problem of the British Engineer.

Some overseas observers have suggested that the principal obstacle to the development of British engineering export is in the engineer himself. No representative selling organisation exists in any branch of the British metal manufacturing, engineering, and shipbuilding industries. Hitherto the industrial, not the commercial, the productive, not the talkative, motive has dominated every department of engineering activity. The desire to excel in workmanship, in organising ability, in inventiveness, and practical capability has been the inspiration of the men whose ships outnumber all others on the seas and fill the harbours of the world; who built most of the railways of India, China, South America, South Africa, New Zealand, and Australia; whose spinning frames hum in the factories of Bombay and Brazil, Lancashire, and Russia; whose creations make civilised life possible over wide spaces of the earth which else had been desolate. Like Dick Helder, the British engineer can say, "Alone I did it." Moreover,

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he may point to agencies and depots, branch works, and large organisations established for productive work in many foreign lands, and ask the new salesmanship what it has to teach him. From every quarter comes the answer, that only by allying himself with the movement that brings all things into the market-place, by spreading knowledge of his powers to serve them among the younger generations of mankind in all quarters of the globe, can his usefulness continue. Already British engineers are beginning to realise the irresistible force of the tendency, but the task of organising salesmanship in Great Britain is not easy. In France, Germany, Italy, Belgium, and the United States, there are strong powers endowed with authority to unite the national industries for any given purpose, but the organisations in Great Britain are weak in comparison. But a Marketing Board now exists, and there are voluntary associations at work which may be strengthened for publicity purposes, for the diffusion of news advantageous to the engineering and shipbuilding industries, and for penetrating markets overseas by the wise distribution of information. As in the years gone, the engineering industries of Great Britain may be trusted to find in themselves the power to solve any problem.

Discussion.

Mr. W. G. Traquair (Member): Most of us, I dare say, are pretty well tired of reading speeches and journalistic articles in which the backwardness of British engineers in the race for world trade is deplored, but I think that in this survey of the subject we are fortunate in having for inclusion in our transactions a most temperate and comprehensive statement of the whole question, and one which, it is to be hoped, may receive the consideration which it deserves from those in a position to act upon its lessons.

One of the leading ideas underlying Mr. Murphy's argument seems to me to be that times are changing, and that any industry which is to survive must adapt itself to its changing

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Mr. W. G. Traquair.

environment, or perish. Of the changes which are taking place, I think Mr. Murphy is right in pointing out that, under modern conditions, the marketing of engineering manufactures calls for almost as much skill, energy, and outlay as does their production. From this it follows that the directors of engineering industry, in addition to being expert in the scientific, executive, and financial sides of their calling, must also devote equal thought and effort to perfecting their organisation for finding buyers for the output of their works.

The allegation that British firms are backward in the provision of catalogues printed in foreign languages, and that they do not supply dimensions and weights in metric figures, has been repeatedly made for many years past, and if it still remains a well-founded charge, it seems to me to be most lamentable and difficult to excuse. Apart from the uselessness of issuing literature which is unintelligible to the majority of persons whom it is desired to reach, the unfortunate indirect effect of such a futile course of action, when compared with the contrary methods of our competitors, must do much to counteract the good opinion which British engineering productions earn for their makers by reason of their superior durability and efficiency.

The same applies to the charge that British engineers do not study the requirements of individual countries, but adhere to a "take it or leave it" policy. This attitude calls for active redress by the paying of repeated visits to foreign markets, on the part of leading men in the industry, in order to make a close study of the requirements on the spot. Such a study would, in many cases, result not only in British firms being able to offer what the customer desires to buy (and this is half the battle), but also would probably reveal means of meeting these requirements at a lower and more competitive cost than is at present considered possible.

The advancing importance of the selling side of engineering industry points to the urgent necessity for the training of a body of thoroughly educated men for this branch of service, who will be as well equipped in the commercial sphere as are

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their colleagues on the scientific side. In this connection, I submit that the time has come when either our University or Commercial College should provide a course of study, leading up to a definite diploma, for men who are destined to devote their lives to the sale of engineering products, both at home and abroad, especially the latter. The curriculum would include the study of foreign languages, commercial geography, foreign banking and exchange, transport and tariff questions, advertising in foreign countries, and many other kindred subjects, knowledge of which at the present has to be picked up incidentally and casually by men who drift almost haphazard into the foreign selling field.

While it seems to me very welcome that a paper such as Mr. Murphy's, which is more of a commercial than of a technical character, should be read before our Institution, I feel, nevertheless, that if good is to result from it the matter must be tackled by an organisation of a more distinctly commercial character, such as the Glasgow Chamber of Commerce; and it seems to me to be remarkable that in a centre such as Glasgow the engineering and shipbuilding industries are not more prominently represented in the counsels of the local Chamber of Commerce. Is it not desirable that on that body there should be a strong section or committee, composed of representative members of our industries, who would devote themselves to the constant study of questions of home and foreign trading, from the special point of view of engineering and shipbuilding, and who would keep that point of view prominently before the main body of the Chamber, and through the Glasgow Chamber secure co-operation with similar bodies throughout the country? Such a committee, moreover, would form the channel through which important information and advices received from all parts of the world, relating to our trade, could be authoritatively and officially communicated to firms in the district who might be likely to profit by it. In the case of at least three other Chambers, namely, those of Manchester, Birmingham, and Bradford, there are Engineering Sections, and if this course is worth

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while in Lancashire, Yorkshire, and the Midlands, I should think that it is no less so in the West of Scotland. The remedy is in the hands of the leaders of our industry in this district.

In the concluding portion of his paper, Mr. Murphy, with characteristic fairness, makes reference to some of the favourable aspects of the situation, and there is much that can be truly said in this respect. His mention of voluntary associations which are at work presumably relates to such bodies as the B.E.A.M.A. and the British Engineers Association. Voluntary co-operative effort, such as is pursued by these organisations, in the direction of studying foreign markets, and the dissemination of information regarding British engineering goods in those markets, is, I think, very much to be encouraged, and it is good to hear from Mr. Murphy that such efforts may be strengthened.

The final sentence of the paper, "As in the years gone, the engineering industries of Great Britain may be trusted to find in themselves the power to solve any problem," doubtless contains much truth, but I venture to submit that it may be a dangerous policy to place much reliance, with an easy optimism, upon the past. Let us rather remind ourselves of the fable of the hare and the tortoise. The ability of the hare to win the race was not in doubt, but, nevertheless, the hare did not win, but was caught napping. The moral, as applied to the present case, is obvious.

Mr. H. H. A. Greer (Member of Council): As an Associate of the Institution, I would like to say that I appreciate the fact that the Institution enables commercial men like myself to gain information on the technical side of the business in which they are engaged. It should not be forgotten, however, that Associates of the Institution do very important work. I was told once that technical institutions had far too many commercial men amongst their members, but I consider it is necessary for us nowadays to know something of the work being done by the practical and engineering members.

A year or two ago I was travelling through Spain, and was

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surprised to find in the smoking and reading rooms of the hotels the technical journals of almost every country but Britain. Indeed, it was a rarity to come across a British paper at all. Even in the Grand Hotel in Madrid not a single British technical paper could be had. This is a state of affairs which I hope will soon be remedied. I found also that we are very often classed with the Americans, and, I am sorry to say, it is not always to our benefit. The American speaks the same language, very largely, as we do, but he assumes a very aggressive manner, and is far from liked on the Continent. I am of the opinion, therefore, that the British traveller should be sent out to counteract that bad influence.

Mr. William Brown (Member): I remember hearing Sir William Larke say, about two years ago, that when there was a failure in a business, either commercially or technically, the commercial side had a human tendency to put the failure down to the inability of the technical side to make what could be sold, and for the technical side to blame the commercial side for being incapable of selling the best stuff ever produced. Mr. Murphy does not blame either side, but he puts his finger on the weak spot of British selling organisation, and if the disease is correctly diagnosed, the cure will be more or less easy. He divides his paper into three parts. Firstly, historical, which does not offer any scope for discussion; secondly, criticisms from men overseas who are actually on the spot, and, therefore, able to state exactly the special conditions in their particular part of the world, and unless we have visited these places and are acquainted with the conditions, we must accept without criticism, but with thanks, the testimonies of these men; thirdly, and all too briefly, Mr. Murphy boldly attacks the problem, and shows how British firms must adjust themselves to new conditions if they wish to have a place in the world's markets.

Mr. Murphy deals principally with the need of advertising our wares. While admitting that the need is great, I might say that British goods are their own advertisement. He

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fears much from America. American goods are made to be *sold*, not used, and while they display much ingenuity in design, these goods do not stand the test of time like British products. Consequently, they require complex advertising. Again, as far as price is concerned, America should not be able to compete very seriously with Britain in the world's markets, as, owing to their gold standard, other countries have an advantage over America. Unfortunately for us, the same cannot be said of our European competitors, and it is all too true that our foreign orders do not receive the attention they merit. I have been told, on reliable authority, that the cost of U.S. bars and tubes in Canada is practically the same as that of British-made goods of the same nature, but that the former are preferred because they are properly crated and arrive at their destination in good condition.

The translation of catalogues into the proper language is a most necessary thing if business is to be developed in a particular country, and it seems to me that an excellent opportunity presents itself for a company of capable linguists setting up in business, and undertaking work of this kind. There is certainly ample scope, and it would be a boon to the smaller firms to have their correspondence correctly translated.

It would be well if one of our numerous Government departments could finance home firms to a sufficient extent to enable them to accept and execute foreign orders. The Belgian Government advances to 55 per cent., with advantage to buyer, seller, and the country generally, and in these times of stress why should we not do likewise?

Mr. C. R. H. Bonn (Associate Member): With the virtues and failings of the British engineer we are naturally very well acquainted, but what of the virtues and failings of the British press? Mr. Murphy states that many parts of the world depend upon information and news disseminated by Germany, the United States, and other countries. Mr. Murphy knows that British engineers who keep up to date with the

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accelerating advance of science and industry must perforce peruse foreign technical literature in the original language. In the British press there is a dearth of translations of important foreign technical articles, particularly of those originating in Germany and Italy, and with little or no acquaintance with foreign languages or with physics, how can our journalists keep the British public clearly informed of scientific advancement and foreign progress? If there is aristocratic pretence in industry, it is as nothing to the aristocratic pretence of the press. In whose interests did the press keep silent when Continental countries, by the national sacrifice of depreciating their currencies, were liquidating their internal debts in the interests of national efficiency? Why did the press not call the country's attention to the possibility of relieving the crushing load placed upon our industry by paying paper interest on paper loans?

Before the press can guide us, with intelligent criticism, in re-establishing our industries, and before it can substantiate its long-asserted claim to represent public opinion, it must change its attitude. Propaganda can only sell goods when the goods measure up to the claims made for them; not one person in ten thousand bothers about where the goods come from. The press must get to understand that organisation in industry is something quite different from regimentation, and has as its essential foundation equitable reward. In matters scientific, technical, and industrial, only those should be employed who are fully qualified by education and training, even as the press of the United States employs its "trained seals," and that of the Continent its scientific collaborators. The personal touch must be introduced by giving due recognition, irrespective of their standing in life, to those who, by their efforts, advance science, industry, and trade. At present recognition is measured by power to influence advertising, and the most deserving are neglected. Who is to blame if to the general public our industry is a profound mystery, and to the rest of the world of no interest at all?

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I should like to stress this point of recognition because of its importance. Recognition has inspired the best types of creator from time immemorial, and it is a pretence to say that the average man does not desire recognition.

It is of vital importance that this country should take an interest in science and progress, if it is to take its proper place in the world, and that can only be done by introducing us to the personality of our industry. I think our press would be well advised to copy foreign editors in the kindly consideration they extend to their contributors. Little courtesies, which, after all, are prompted by a true intelligence, have changed the destinies of men and states.

Mr. W. E. PHILBROW (Member): The subject matter of Mr. Murphy's most inspiring paper requires very close consideration, otherwise we may be alarmed with the prospect of the failure of our engineering and allied industries in the face of determined foreign competition. The paper is in itself self-contained, because the solution of the difficulties stated to exist is given in the final paragraph—"the engineering industries of Great Britain may be trusted to find in themselves the power to solve any problem." With all due respect to the outside authorities quoted, I submit that our engineering industry is not so inefficient in selling their manufactures as Mr. Murphy suggests.

The volume of export sales of any commodity depends on the financial facilities available, and in recent years the opportunity to invest in first-class securities at high rates of interest at home has been so wide, that our financial authorities have no need to undertake the support of more speculative investments abroad. Compared with the American or German outlook on financial facilities, our own bankers are apparently conservative.

Mr. Murphy includes almost every branch of engineering (except the electrical industry) as subject to criticism of their export activities, but I would consider shipbuilding to be largely engaged in supplying the home and not the

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export market. The supply of material for railways will also be through the home market, because a big percentage of railways outside of national or state undertakings were established and are financed by the British nation.

Further, different classes of goods require and are provided with totally different methods and organisations for export sale. Mr. Murphy does not give sufficient credit to the highly efficient merchanting and agency system carried on in all parts of the world on an enormous scale by British firms. These people are established in every country, and handle what might be termed semi-finished materials in bulk, and are the real advertisers of the goods required by different countries; it is unjust to insinuate that such people are not so able as the Americans or Germans.

Then there are what may be defined as the heavy machinery supplies, such as power station, mining, or complete factory equipment. This market is supplied largely by personal negotiation, as it will be obvious that no firm or corporation will speculate large sums of money on plant without most careful investigation, and the provision of the actual money has to be arranged. In addition, most British firms specialising in such machinery send out able technical men and assistants to review and negotiate on the spot. Possibly these men do not travel with the "bounce" of the American, but they do secure the business, and are welcomed by the class of potential customers desired by their employers.

Finally, there is the smaller special and standard machinery, such as unit boilers, steam and internal-combustion engines, pumps, agricultural implements, etc., supplied by what might be defined as manufacturing engineers, and mostly suitable for introduction and sale by means of trade catalogues.

The criticisms submitted in the paper will no doubt apply mostly to the marketing of this class of machinery, involving problems of advertising, personal canvassing, demonstration and showrooms, to secure the interest of the individual pur-

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chaser. It must be admitted that our German competitors are ahead in the provision of showrooms and in the personal quality of their travellers, who frequently are men with high-grade technical and commercial education. The "cheaper" British method is that of working through an agent paid on a commission basis, while the American uses a "live" salesman, backed by profuse, well-illustrated literature and ample funds to secure the sympathy of influences surrounding the potential customer. The American outlook is opposed to the British, as the American is indifferent to the lasting qualities of the goods he has to offer, and looks forward to the prospect of selling an "improved" machine on his second visit, whereas the Britisher endeavours to provide lasting qualities, and to secure future custom by reputation.

All the critics reiterate the desirability of supplying catalogues and data in the language of the potential customer, and we must agree with this opinion, but America and Germany are not superior to Britain in this respect. Many lists are received in this country printed in the language and using the measurements and prices common to the country of origin, or very poor translations. A number of British manufacturing engineers supply catalogues printed in foreign languages, but the difficulty is to provide a language to suit countries far apart but using the same basic language; Spain or South America may be cited as an outstanding example of this difficulty.

The provision of free technical journals has yet to be proved a successful commercial proposition, and an inspection of the advertisement columns of such journals will disclose the large percentage of small machines which are advertised, bordering on domestic goods, usually distributed from this country through merchants. One method of meeting this type of competition would be for several firms to co-operate on an advertising and personal canvassing campaign. The problem of selling on deferred terms depends solely on the financial support available, and not on the knowledge or ability of the manufacturer.

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Recently America has become the creditor nation of the world, with a surplus of manufacturing facilities and money. In consequence, she is able to spend the excess cheap money freely to secure the disposal of the surplus manufactured. The question arises: Is this method of literally buying immediate business more sound and beneficial than the British method of selling only to the customer able to pay for the goods on or within a month or so of delivery? It is fairly well known that the immediate market for machinery could be largely extended, provided some financial support could be ensured. One note of optimism runs through the criticism from foreign consuls, and that is the admission of the splendid reputation established by British manufacturers for their goods and business methods. Surely this is the best of advertisements, and the engineering industry deserves credit for such a reputation.

The security of our future trade within the Empire rests more in the hands of the politicians and publicists than the manufacturer, by more efficient handling of the problem of repeopling the vacant spaces. At present we treat intending emigrants as unworthy wasters, and are only prepared to assist the agricultural labourer; even he is left to the haphazard, crudely commercial mercies of the shipping agents, and leaves this country with more or less bitter memories. Every effort should be made to send a large percentage of people with a more advanced outlook, and all emigrants should be treated in the most generous manner, so that they will leave this country with the sense of still being one of ourselves and a feeling of goodwill to those that remain. The establishment of goodwill is the foundation of commerce, and is by far the most powerful selling force.

Without question, Mr. Murphy's intentions are for the good of the industry, but it seems to me that he is inclined to accept the critical opinions of people without real knowledge of the facts. The export trade of this country would certainly improve if our publicists were restrained from broadcasting so much hostile criticism of British industries.

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Mr. JAMES ANDERSON (Member): Mr. Murphy refers to a report on British trade with Poland, and it occurs to me to ask: How many engineers know anything about the laws of the country with which they propose to trade? As an example, I will cite the case of Russia. In pre-war days British manufacturers had to be very careful in dealing with Russian firms, because, although the latter might have quite good bank references, they could if they wished "go under Administration." This was somewhat similar to the appointment of a Liquidator or Receiver, but with the important difference that, while the Administrator could collect all the debts of the firm, he could refuse to honour the liabilities. So far as I understand, there are some curious points in Polish law of the same nature.

I believe that we have as clever engineers and as clever salesmen as any other country, but there are certain things lacking. An organiser of sales throughout the world would require to be conversant with foreign languages, principally French, German, and Spanish, and to be an engineer with an additional commercial training. It seems to me that such a person would be almost a superman, and, as supermen are yet very rare, a compromise must be found. The solution appears to lie in the financing of export business. While the present banks fulfil a very useful function, they are not trade banks, and I suggest that such a bank be formed by engineers. All the firms who subscribed would do so in proportion to their capital, and then take another allotment of shares in proportion to their turnover or output. There would be branches in, say, Germany, France, and South America, etc., with a representative thoroughly conversant with engineering, and with the language and customs of the country in which he is stationed. If, for example, motor cars were wanted in South America, the agent would immediately communicate with the bank, who would in turn inform the motor-car manufacturers that a certain size of car was in demand in South America. Every manufacturer of cars connected with the Association would send out tenders, which would be put before the people concerned by the bank agent. Then when the order was

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placed, the successful firm could go to the bank and arrange to receive payment over a period of, say, 12 months. They would be financed, first of all, for the value of the order on the shares which they held in relation to their capital, and would be further financed by credit for the 12 months in proportion to the share capital held on the output basis.

Mr. D. M. Semple: Mr. Murphy's paper is a good clear statement of the problems confronting all manufacturers of export products in this country to-day. An engineering business now has two distinct and separate branches—selling and manufacturing. Selling is advisedly placed first, because the best designing ability and manufacturing facilities are useless unless an outlet has been found for the product.

Selling is an art calling for the greatest skill. The successful sales manager must first be convinced that he is selling the best product, and must be able to tell why it is the best. He must discover his markets from the study of statistics; select his men, and be the connecting link between them and the factory, keeping all of them advised of developments at home; he must arrange advertising campaigns; and, above all, he should visit the countries in which most business is done, so as to gain some first-hand knowledge of local conditions.

For sales engineers, it is not always possible to engage older men experienced in the ways and language of any particular country, as the salaries such men can command in these countries may be higher than a newly-formed agency can afford to pay. The next best solution of the problem is to choose a well-educated young man from home, one with a good knowledge of the firm's products. He will soon accommodate himself to the customs of the country, and learn the language What he lacks in experience will be compensated for by enthusiasm and the energy of youth.

Mr. James Gillespie (Member): That Mr. Murphy's paper has great potential value cannot be gainsaid in that it provides food for thought. Once again he emphasises the fact

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that we are labouring under the handicap of a diminishing overseas outlet for our engineering and allied trades' manufactures, and if the discussion brings about some corporate action which will tend to eliminate the predisposing causes of this deplorable shrinkage of our share of the world's trade, then he will deserve our gratitude.

The contention that an improved method of salesmanship would be a step in the right direction is unquestionably sound, but that is only touching the fringe of the problem, and we must seek elsewhere if our efforts to resuscitate our dying industries are to be crowned with success. When Mr. Murphy asserts that in bygone years the force of enlightened public opinion acted as a spur to goad the manufacturers of certain products into setting their houses in order, he deals with conditions which have no counterpart to-day. As he rightly says, we are "dealing with a changed world," and equally has the force of public opinion changed. Taking a somewhat parochial view of this aspect, it may be recalled how frequently have some of our most advanced and energetic local concerns been driven into the Courts, to plead for such an adjustment of rateable assessment of their plants as will enable them to continue to manufacture without loss. How meagre have been the results of these pleadings! Had a healthy public opinion existed, it would have compelled some reasonable diminution of these exactions. These cases were blazoned in the public press; they were common knowledge; but they were forgotten in a day. This is surely indicative of the general trend of affairs when men, industries, and nations are acting on the selfish injunction, "man mind thyself." The truth is that each member of the public is so engrossed in his own efforts to meet the rapacious demands of rate collector and tax gatherer that he has little time, and no sympathy to spare for his brothers in affliction. That still another concern, whose name has been a household word for a generation or more, has been taxed out of existence matters but little to the toiler whose only thought is how to escape a similar fate.

Turning to the very succinct "Advices from Overseas," the

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reader is struck by the two facts which so boldly emerge: that our goods are of the highest standard; and that in the opinion of our consular officers they are badly marketed. There is no disputing the first of these. The Schneider Cup race and the performance of the G.W.R. locomotive in the U.S.A. are recent confirmations of this, but to put a proper value on the second requires some little consideration. It is idle to discuss lightly these writings of our consuls. Doubtless some fundament of truth lies behind what at the first blush would appear to be a sweeping condemnation of our methods. Let us then critically examine the engineer's training as a salesman in relation to the consul's qualifications to act as his mentor. We have knowledge that the engineer has spent a lifetime in gaining experience of how to dispose of his products in all sectors of the world, and surely no one will deny that to have succeeded so far he must have at least some idea of his markets. We must concede that he has accomplished something to entitle him to a small meed of praise. Have we an equal knowledge of those members of the consular service who so kindly criticise our apparent shortcomings? Are they specially selected on account of their intimate knowledge of engineering or some kindred trade, or are they merely the successful from out the hosts of seekers of political patronage, and if they are one or the other, what have they accomplished that they should so tenderly absolve us from the necessity of wiping the mote from our own eye?

If these gentlemen are taken at their own valuation, it must be assumed that their first duty is to provide information and lend assistance to the representatives of those firms who seek their markets abroad. As a means of ascertaining how well this duty is performed, I put the following question to 24 engineers and others who habitually deal with foreign business: "Have you at any time received from the consular service such advice and information as has enabled you to secure an order which, in the absence of such information, would have gone past you to a foreign competitor?" I may have been unfortunate in my selection, yet the fact remains that I

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received 24 negative answers. Not only so, but in some cases at least the question so appealed to my friends' sense of the ludicrous that I have acquired an undeserved reputation as a wit. Now this experience need not be held to be conclusive, nor is there any need to base on it a wholesale condemnation of the service, but we can at least seriously question the right of those well-meaning gentlemen to attempt to stampede us into increasing our expenditure on overseas advertising, etc., an increase from which a return is more than problematical.

Trade is based on the fundamental law of supply and demand, and what limits and restricts demand is the ability of the potential purchaser to pay the price. It is a fact that this country is not now able to manufacture at prices low enough to entice the foreign buyer to lay aside his coyness, and the reason for this is not far to seek. Time was when Britain was dubbed the "workshop of the world," and that now she is the "taxpayer of the world" is at once reflected in her declining foreign trade returns. Remove the iniquitous exactions of the tax gatherer, curtail the powers of the tax squanderer, and our trade will return, as surely as night follows day. If our manufacturing houses were taxed on the same scale as their Continental and American competitors, the country would soon be a hive of industry, and overseas representatives would be at a discount, because the foreign buyer would himself resort to our exchanges as he did when taxes were at a reasonable level. That this is no unsupported assertion is instanced by a glance at the condition of the motor-cycle industry. Here is an instance of the foreign buyer coming to place his business simply by reason of the high-class British article being sold at the right price.

The heavy engineering industry would soon be in the same happy position if only the Jacks in office could be compelled to cease draining the country of its life's blood. Is it not possible to unite the manufacturers of Great Britain into one gigantic federation which could dictate terms to the political "bosses"? Then they might be in a position to say "We

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cannot and will not pay more in taxation than the foreign competitors who are filching our trade."

In the quality of our products we are still unexcelled, but until these can be sold at prices to compel interest in them, it is quite immaterial whether or not these sales representatives are polyglots. It is doubtless true that some of our workshop equipment is out of date, but until that happy day when the prospect of making ends meet is brought nearer, there will be extreme difficulty in finding money to modernise it. It is equally undeniable that money to finance foreign contracts is hard to find; so long as we have to find money to fill the coffers of our late transatlantic allies, these conditions will obtain, and it is not too much to say that this transference of wealth is tantamount to putting the British manufacturer into the position of financing the foreign contracts of his rivals. The overseas ambassador of commerce in normal times serves a useful purpose, but in times like these the action of sending him abroad upon our lawful occasions is wellnigh useless.

Mr. MURPHY: When the author of a paper replies to a discussion upon his work, he is supposed to answer criticism, but my paper has received such kind and gentle treatment that my reply must take the form of an appreciative review of the main points raised. The discussion has gratified me, because it shows that serious thought has been given to the problems outlined in the paper. A feature of all the contributions to the discussion is the admission of a certain amount of justice in the contention of the press that British engineers have not attained a desirable degree of efficiency in their salesmanship overseas. But Mr. Bonn turns the tables upon the press by calling attention to its own sins, which are admittedly serious. There can be no doubt that the press of this country has misrepresented the engineering industry in various ways. Pressmen have sent abroad items of news that were of no importance, but because they happened to have a kind of sensational appeal they were broadcast all over the world, with the result that these trifles represented to the foreign mind the

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actual state of the British engineering industry. Admittedly, that has been wholly unfair; but, on the other hand, engineers have not been quite fair to the press. They keep the facts concerning their business to themselves. They do not announce their contracts, or, at any rate, as often as they ought. In fact, they do not let the press know what is actually going on in the industry.

There is a nobility of temper in that reticence, but in these times Carlyle's "gospel of silence" is out of date. The advertiser is abroad, and has power. The publicity man has great influence. The general mass of the public look to him for information and instruction, and business men pay heed to his word. Therefore, the engineers of Scotland might consider whether they ought not to give a little more attention to the publicity side and the salesmanship side of business than they have hitherto considered necessary. For instance, I have been out of Glasgow for some time, and coming back fresh I have been struck by the greater splendour of the shops, with the daylight signs, with the vast increase of sales display that appears in Glasgow streets. What is the meaning of that? It is the manifestation of an economic movement which is showing itself everywhere. In every department of industry and commerce, even in engineering, there is the movement towards display arising from the discovery of the advantage of spreading abroad knowledge of the things which are for sale or the commodities made for use. The tendency is irresistible, and it seems advisable that the engineers of this country should devote more attention to the organisation of their salesmanship, especially in lands overseas.

Perhaps in being frank I may tread on someone's corns, but my experience is that many engineering firms regard the publicity department as a place where an engineer who has not succeeded in his profession might very well find suitable employment. Hitherto, as a rule, the function of the salesman has been placed on a level too low, and it would be nearer the right measure if the salesman were required to show as much ability as the practical manager of a department in the

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works. That is not the general practice of engineers, but I do not agree with the comparisons frequently instituted between British methods of publicity and those of Germans and Americans. The inference always is that we are inefficient, and that our competitors are always expert; but having had some experience of foreign methods of publicity, I cannot admit the truth of the proposition. Once I was asked to review the textiles volume of a huge German technical dictionary, and found many errors in it, one of the simplest being the definition of a "pilot cloth" as a cotton fabric, when, in fact, it is a heavy woollen cloth. We are often accused of making bad translations into foreign languages, but I have never seen one so bad as that of the Frenchman who defined the lead screw of a lathe as "the screw which is made of lead." These are only trifling instances, and they must be taken as mere indications of the inefficiency I have observed in the technical publicity of foreigners. Mr. Philbrow, however, has handled that aspect of the subject so ably, and vindicated the relative publicity ability of the British engineer so thoroughly, that nothing is left to me but agreement with his observations. British manufacturing firms supply catalogues printed in foreign languages that are models of their kind, but there is no harm in wishing that there were more of them. Engineers could easily add to the number with advantage.

I do not agree with Mr. Philbrow when he says "The provision of free technical journals has yet to be proved a successful commercial proposition," for the journal with which I am connected has been a financial success, and it does not contain advertisements of small machines, "bordering on domestic goods." This is not the place to discuss that, but it should be known to British engineers generally that there are trade and technical journals published in this country which, though largely supported by subscribers, are widely distributed free in South America, Australia, New Zealand, and other countries, copies being sent to Chambers of Trade, hotels, and railway depots, as well as to known consumers of engineering products who do not happen to be on the sub-

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scription lists of the journals. Mr. Philbrow's last remark on the ignorance of the critics of British engineering overseas propaganda is just, but the criticisms I have quoted come from members of the ablest body of men ever engaged in the service of any nation. That our consuls and commercial secretaries in foreign countries occasionally make mistakes when dealing with trade technicalities cannot be denied, but on the whole they are marvellously right. If engineers would come into closer touch with the Department of Overseas Trade, the risk of such mistakes would be greatly lessened, and they would learn a great deal that would help to solve their trade problems overseas.

Mr. Anderson's suggestion that a body should be formed to finance export business is in line with the most advanced thought and practice of the day. Mr. Sam Mavor, who was unable to contribute directly to this discussion, in the course of conversation said my failure to note the Export Credits Scheme set up by the Government was a serious omission. He thought the scheme should be made better known to British engineers, and also to purchasers of British engineering products in lands overseas, because it afforded great advantages both to the purchaser and the producer. Mr. Semple does not think the work of salesmanship worthy of the efforts of a trained and mature engineer, and perhaps his suggestion of a well-educated young man thoroughly acquainted with his firm's products, is the "next best," and might well be acted upon.

Mr. Gillespie, with a severity that seems based on some unsatisfactory experiences, states the whole case from the standpoint of the engineer. Undoubtedly the British engineer is handicapped by heavy local rates and imperial taxation, and by other difficulties not of his own making; but these are only some of the problems which it has been my endeavour to provoke him, not without sympathy, into solving.

Mr. Traquair, in his kindly contribution to the discussion, suggests that I am somewhat too optimistic in regard to British engineering. But I cannot agree. For over 30 years it has

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Mr. William S. Murphy.

been my business to view engineering activities from an outside point of view, and I have been imbued with a great faith in the ability and efficiency of the British engineer. In years gone by I encountered Mr. Walter Brock, Dr. John Inglis, and many other members of this Institution who contributed powerfully to the development of the engineering industry, and I do not believe they are without fit successors. On the contrary, my observations lead me to believe that British engineers, the engineers and shipbuilders of the Clyde, are as capable to-day as ever they were. They must, however, have a clearer and stronger faith in their own powers, and endeavour to persuade the buyers and users of engineering products in lands overseas to share that faith.

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CITY LOCAL PASSENGER TRANSPORT.

By W. C. Easton, B.Sc.,
Member of the Institution.

8th November, 1927.

1. The whole question of transport in this country is in a chaotic condition. This is a consequence of the war; of the post-war adoption, no doubt under stress, of hurried and one-sided methods; and lastly, of the enormous increase in motor transport. The number of motor vehicles on the roads has practically doubled in the five years between 1921-1926.

2. After much talk of economy, a halt in expenditure is, rightly, being enforced. This is no time for launching out into large capital expenditure. It is, however, the time for endeavouring to think out problems, as a whole, in a considered, deliberate manner. This paper is the commencement of an endeavour to do so, on the question of City Local Passenger Transport.

City local passenger transport is confined to that section of the transport problem which deals with passenger transport from the centre of a city to its immediate fringes, say, from the centre to beyond an inner radius of three miles, but within an outer radius of ten miles. The other sections of the problem, Fig. 1, will not be mentioned further than is necessary to envisage the whole.

3. The essential is to consider the needs of the future. Fifty years ahead is not too much. There may be city traffic troubles to-day, notwithstanding dull trade; but trade will improve, and with that the increase in traffic, and particularly motor traffic, will continue still more rapidly. City traffic

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difficulties will thus inevitably become greater, and make city local passenger transport, if still on the streets, so slow as to

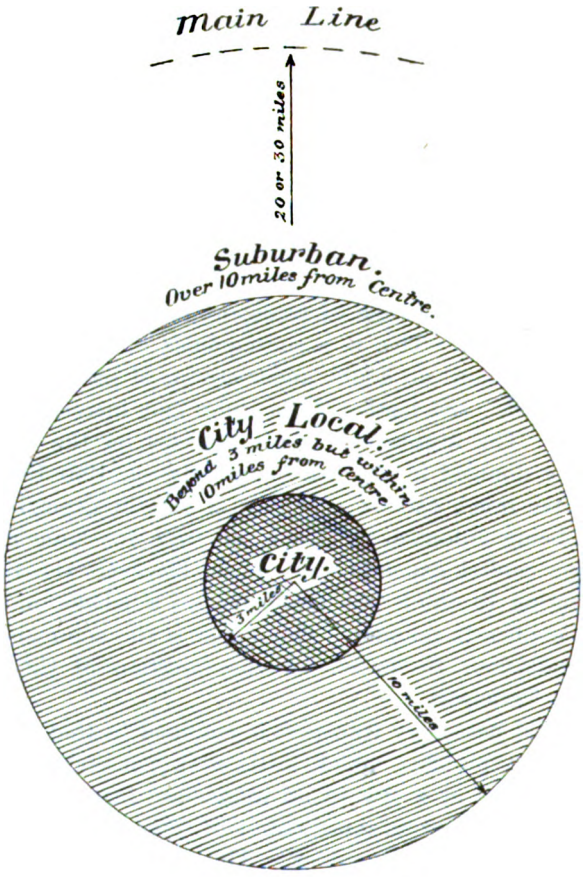

Fig. 1.

be valueless except for persons of leisure. Further, the transport question will never become stationary. Any methods adopted must, therefore, permit of gradual, but extensive, development as required.

4. The remaining sections of the problem which must

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necessarily be mentioned are city transport, suburban transport, and main-line transport. City transport is obviously transport within the city area proper, *i.e.*, within the inner radius of city local transport, which at the moment, in most cities, it controls. The other two sections are obviously outwith the outer radius of city local transport.

Transport Generally.

5. A reference to transport generally would be incomplete to-day without mentioning the latest method, namely, aviation. Its relevancy is that it illustrates two most important points of general application. The one, W, is the almost unlimited space available not only in the horizontal but also in the vertical plane. This almost completely removes all restriction on speed. The other, X, is the fact that even two aeroplanes flying on the same horizontal plane cannot cross the same point at the same time. This is vividly illustrated by disasters —fortunately few—which do occur even in the air. But for this possibility the word "almost," twice used under W, could be eliminated. As will be seen later, these two points are of vital importance in the problem of city local passenger transport.

6. Coming now to the relevant forms of transport, these are, generally speaking, two, namely, road and railway. Road transport is the older, and road construction is a public service carried out at the expense of the public. The most crisp definition of a road or highway is that quoted at the beginning of Chapter II of Ferguson on the Law of Roads, Streets, etc. It reads:—

> "A highway is a right of passage in general to all the King's subjects without distinction."

Sir Lynden Macassey, speaking at the Institution of Civil Engineers* in 1910, made some interesting remarks on the way

* Vol. clxxxiii, p. 63, Discussion on "Holborn-to-Strand Improvement."

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in which use and wont had operated in this country. The following is the relevant quotation:—

> ". . . It would seem that the English notion of a street was a yard which might be used for the purposes of the trade of the persons living in the street, and which, so far as they did not require to use it for their vans and carts, might be used for purposes of locomotion."

That is clearly an extreme view of the rights of the frontager, who obviously must have some rights. Even in city streets it is undesirable, in the interests of the city itself, that these frontagers' rights be entirely extinguished. As regards right of passage, until recent years the roads and the city streets were ample to accommodate the needs of all the King's subjects, whether for their use as individuals or as public road carriers of passengers and goods. The public road carrier is of long standing. To-day he is represented by the large commercial road transport concerns, carrying chiefly passengers, but also goods.

For convenience, the words "commercial transport," whether qualified by the word "passenger" or not, are herein used to mean transport carried by commercial transport concerns, as public carriers, whether by road or by rail. They do not cover vehicles owned, or hired, by individuals for the conveyance of themselves or of their own goods.

7. Railways differ from roads in that, although equally for the public service, they are constructed by commercial transport concerns, namely, the railway companies, who alone have the right to use them. Until quite recently all railways served for the transport of goods as well as of passengers.

8. A brief summary of the main conditions under which commercial transport concerns have to work is now desirable. At the one extreme there are the railways, and to these the following conditions apply:—

1. Railways are made under statutory powers. These powers impose on them certain statutory duties and restrictions.

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2. The railway companies pay for:—

(a) The land through which their lines are laid.
(b) The construction of their lines, including a highly developed and expensive system of signalling.
(c) The maintenance of their lines.
(d) The rates and taxes on the valuation of their lines.

At the other extreme, there are road transport concerns other than tramways. Until quite recently, at least, they were free, and are still largely free, from the permissions and restrictions under item 1 as regards railways. Similarly, as regards their lines—not to mention most of their stations—they only pay a contribution to one, sub-item (c), the maintenance of their lines, *i.e.*, the roads, out of the four sub-items for which the railways have to pay.

Between these two extremes come tramways, which, generally speaking, are subject to all the conditions—except the cost of the land through which their lines are laid and of any expensive system of signalling—mentioned above for railways. They have, however, under sub-item (c), to pay for the maintenance of a substantial portion of road surface used and worn by all other road traffic. Unlike the railways, road transport concerns, including tramways, are not responsible for the supervision and working cost of the signalmen required, *i.e.*, traffic police.

The vexed question of bus *v.* tram is a subsidiary one not relevant to this paper. The question of equity as between roads and railways is equally irrelevant. The real question is—Has this country any use for railways and, in particular, new railways?

City Housing Problem.

9. The key to the solution of the city housing problem is fast and frequent passenger transport. In prosperous cities the business quarter keeps extending. At the same time, its

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occupation, as a business quarter, becomes greatly intensified through the replacement of old buildings by new ones of much greater height and capacity. Coupled with this, there is the demand for the removal of slums and the rehousing of their inhabitants under up-to-date conditions, involving much less density of population per acre. Consequently, the space necessary for city housing can only adequately be obtained on the fringes of the city proper, in the area defined in this paper as that to be served by city local transport, *i.e.*, between an inner radius of three miles and an outer radius of ten miles from the centre.

10. The problem, which has recently become more acute, is the rush hour. Owing to the alteration in working hours, all classes of workers now have, approximately, the same rush hours.

11. The need for considered thinking ahead may be illustrated by facts available this year, 1927. London is admittedly an extreme case; consequently it has already actually encountered, in an acute form, difficulties which other cities ought now to foresee and avoid. Within the last two years there have been held in London at least four relevant public inquiries. Three of these were solely with regard to the alleged inadequacy of travelling facilities directly connected with the housing problem. The fourth was the Bridges Inquiry. There the main issue was cross-river communication. It incidentally confirmed many of the points, consequent on the housing problem, brought out in the other three inquiries.

The fact that fast and frequent passenger transport is the key to the city housing problem was clearly brought out in all these inquiries. Local authority after local authority from the fringes came forward almost unanimously calling for the same solution, namely, a "tube" to their area. By a tube, of course, they meant the fast and frequent passenger transport service now known by that name, whether that be given by an actual tube in tunnel or by an extension thereof on the surface.

The barrier was the question of cost, and many, but not

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quite all, of these local authorities ignored this. When it was pointed out to them, their attitude, with, latterly, certain exceptions, was the too common one to-day of looking for the "dole."

12. Another fact brought out was that the provision of fast and frequent passenger transport ought to precede the building of the houses. Two examples, the one showing how to do it, and the other how not to do it, will suffice.

The first example is the extension of the tube from Golders Green to Edgware. When that extension, which, in the first instance, was from Golders Green to Hendon, approached completion, a walk over the area which is now served was practically through fields. Visits thereafter, at intervals of only six months, showed instantly to the eye the manner in which housing followed fast and frequent passenger transport.

The reverse example is that of the Becontree Housing Scheme, to the east, on the north side of the Thames. There, apparently for unexpected reasons, the construction of the houses preceded the provision of fast and frequent passenger transport. Pages of the evidence are take up by statements, by responsible men, on the troubles consequent thereon —the solution of which is not yet. They are obvious on a visit.

The visible success of the first example was, of course, one of the main factors which caused the other local authorities to demand the same facilities, irrespective of cost.

13. Coming further down the scale to the Glasgow area, there was this year a Conference on Regional Town Planning. The area dealt with was that surrounding Glasgow. It is obviously one in which developments very similar to, but on a smaller scale than, those which have taken place in London must be foreseen; perhaps more so than in any other district in this country. At this conference it was pointed out that the new factor, which compelled a wider envisaging of the problem of regional town planning, was the development of motor transport. The need for co-ordination in town planning and many other very desirable features were dealt with.

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Figures were given indicating the great increase, and the further future increase, of motor transport.

With that possible exception, not a word was said on the fact that the key to city housing was fast and frequent city local passenger transport.

City Local Passenger Transport.

14. *General.* Certain far-seeing cities excepted, the present public means of city local passenger transport are limited to two, namely, Roads, by bus or tramway; and Railways, by suburban and main lines of main-line railway companies.

15. At the moment, the obstacles to city local passenger transport lie not within the area which it is intended to serve, but within the city area proper. They are, generally speaking, the same for roads (in this case streets) and railways. They are the result of the attempt to superimpose on both, traffic which neither was designed to carry.

16. Streets and railways in, and in the vicinity of, a city are main channels which, until recent years, were quite capable of carrying the streams of traffic from the many feeders contributing to them. Faster and more frequent service is now the essential for city local passenger transport. That is beyond the capacity of these streets and railways. For this, there are two outstanding reasons:—

W. These channels are in themselves now too small.

X. Crossings on the level veto both speed and frequency.

W. Insufficient size of channels can be cured by the widening of existing routes, or the provision of additional routes. In a city the use of parallel routes would appear to be a simple solution of this.

X. Crossings on the level are much more difficult to cure, particularly for the streets. Railway routes in this country do not cross each other on the level. At every junction, however, the up-line of the one route has so to cross the down-line of the other.

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It is possible to obviate this by the provision of fly-over crossings. Fig. 2 illustrates one in open country. In a city the difficulty and expense of these are much increased. They are, however, nevertheless, generally quite practicable. City

Railway Fly-Over Crossing

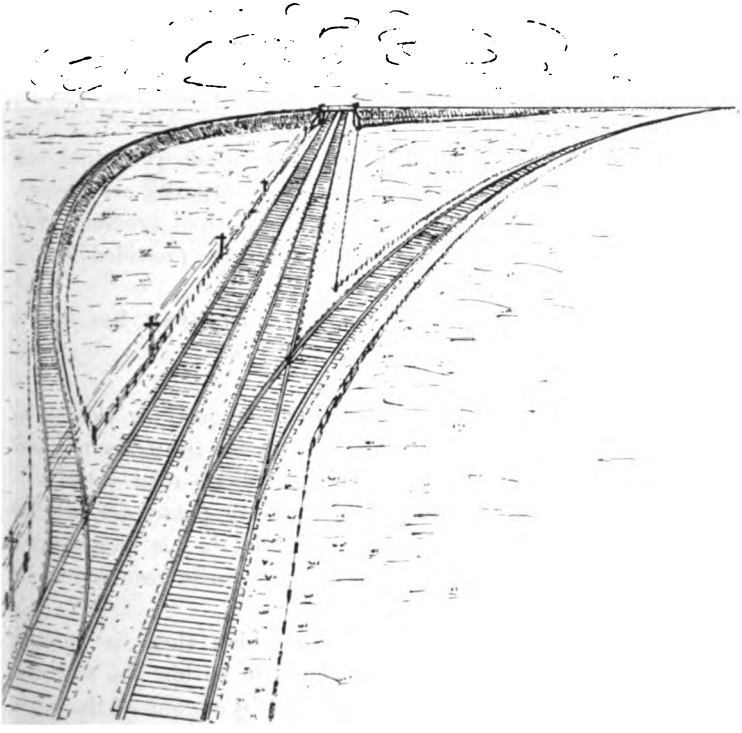

Fig. 2.

streets, on the other hand, do, as a rule, cross each other on the level. Not only so, but traffic at these crossings has also to turn from one route to the other. Consequently, at every street crossing, there is the double difficulty caused by the existence of a route crossing and also junction crossings.

17. These reasons, W and X, represent comprehensively the

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outstanding physical facts. At the critical stage reason W would be more correctly, visually, represented by the letter V. The engineer's problem could thus be summarised as the conversion of V into W and the elimination of X. It now requires some consideration in detail.

18. *City Streets.* The usual city street provides a roadway, measuring 40 feet wide from kerb to kerb, for traffic in both directions. Ten feet is now the accepted width for each traffic stream. A 40-foot street, consequently, gives accommodation for two streams of traffic in each direction, provided the streams are moving.

19. The King's subject, in the form of the pedestrian, still requires some consideration. For him footpaths are provided, but he has to cross the roadway at every street crossing. Subways can, where necessary, as a rule, be provided for this purpose, if he will only use them.

20. The roadway of the average city street has thus to accommodate the following requirements:—

1. The reasonable use by the frontagers for the loading and unloading of goods, and for the convenience of their clients who may use private road vehicles.
2. The King's subject as a roadway passenger, whether on a bicycle or motor bicycle, in his own car or a motor car or horse cab temporarily reserved for his own use.
3. The transport of goods for which there is no other possible means of conveyance within the city area. These goods may be carried by means of the slower horse, or the faster motor transport, in vehicles which may be either private or public service, such as railway companies' vehicles delivering from the nearest railway station.
4. City passenger transport by commercial road transport vehicles within the city area; a service which will necessarily have frequent stops, and be of relatively slow speed.

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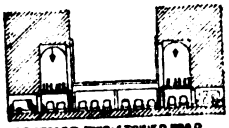
FIG. 2.

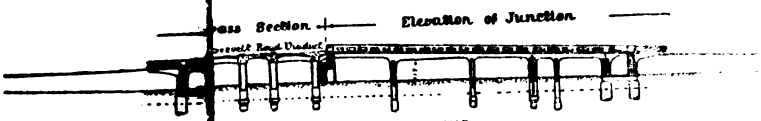
PROPOSED ROAD WITH ELEVATED FOOTWAYS AND WITH OVERHEAD CARRIAGE-WAY. FOOTPATH

FIG. 3.



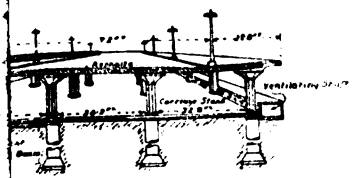
PROPOSED TWO-STORIED ROAD WITH GALLERIES ON THE TOP FOR PEDESTRIANS AND ON THE GROUND LEVEL FOR VEHICLES.

FIG. 4.



VELT ROAD VIADUCT, CHICAGO, AND WITH A TRANSVERSE CARRIAGEWAY

FIG. 5.



OVERHEAD ROADWAY AT ATER STREET, CHICAGO.

Plate 1

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21. It does not seem possible to eliminate any of these four requirements. Faint suggestions, nevertheless, were made at, at least, one of the London inquiries that the use of the main streets during the rush hour should be forbidden to the private motor car—incorrectly referred to as the "Rolls-Royce of the plutocrat."

The tendency is obviously entirely in the other direction. The use of the private motor vehicle will continue to increase rapidly, unless physically checked by congested streets.

22. The superimposing of a fifth and much more severe requirement, namely, the fast and frequent service necessary for city local passenger transport, immediately brings to the front the two main difficulties—W, insufficient size; and X, crossings on the level.

23. The use for W of parallel streets has already been favourably commented on. It, however, only intensifies X. Circuses are, where conditions permit, being used to meet this. Obviously, even where possible, they can only be palliatives.

24. Many suggestions have been put forward to solve these street difficulties. One, which was advocated before one of the recent London inquiries, was to construct great high-level viaducts crossing the city at a height sufficient to pass over all buildings. A height of, possibly, about 200 feet was mentioned. The difficulty of enabling passengers to pass from the ordinary street level to join the fast road transport service on the high-level viaducts was to be met by providing 11 lifts to the mile, *i.e.*, spaced 176 yards apart, along the high-level viaducts.

25. Other more reasoned proposals were reviewed in an excellent paper in "Le Genie Civil" of 16th January, 1926. The diagrams in that paper are so illuminating that, with the kind permission of the editor of "Le Genie Civil," five of them are reproduced on Plate I.

Following is a brief description:—

Fig. 1, Plate I, shows a proposal to widen an existing street by extending the roadway not only over the space previously

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occupied by footpaths, but by galleries extending under the first floor of the adjacent buildings. Provision for the pedestrian was to be given at the first floor level by means of footpaths, cantilevered over the portions of the roadway which had previously been occupied as footpaths.

Fig. 2 is a similar proposal without the galleries under the first floor of the buildings.

Fig. 3 is a still more elaborate proposal, namely, for a two-storey street. The existing street was to be widened at the street level under the whole extent of the adjacent buildings. The first storey street was to occupy the whole of the breadth between the fronts of the buildings. Pedestrians were to be accommodated by galleries at the first storey level under the second floors of the buildings.

Fig. 4 shows in its centre the cross section of the two-storey street of the Roosevelt Road viaduct at Chicago, with, on either side, the inclined way forming the junctions of the first storey with the streets at the ground level.

Fig. 5 shows, to a larger scale, the cross section of the overhead roadway and footpaths of the two-storey street at South Water Street, Chicago.

Not having had the privilege of visiting America, I allow these figures to speak for themselves.

26. An official report, issued in 1924, contains an attractive-looking picture of super-streets for New York. Buildings from 7 to 20 storeys in height are shown 120 feet apart. Between these buildings is shown a two-storey street, generally like Fig. 5, Plate I, but with a vent 4 feet wide, enclosed by hand rails, running down the centre of the first storey, and with a foot pavement, 15 feet wide, alongside the first storey at each building line. This leaves two roadways, each 43 feet wide, and each carrying four traffic streams—in all eight. The ground floor differs in that the foot pavements are only six feet wide, rather significant, leaving a roadway capable of carrying a total of ten streams of traffic, intercepted by five lines of columns. Below the street level is shown a

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four-track subway for the rapid transit system. The report states:—

> "The upper level of the super-streets would, of course, be given over to express motor vehicle traffic entirely. There would be no traffic crossing it. The lower level would be utilised for business traffic."

27. Referring again to difficulty W, clearly the construction of the two-storey street, by doubling the size of the channels, does convert V into W, § 17. The effect of such a two-storey street is another question. It would obviously convert the existing ground-floor shops, etc., into basements—justifying the restriction, noted in § 26, of the foot pavements to 6 feet.

Some slight idea of this may be obtained in Glasgow, in Argyle Street, where the railway bridge crosses that street. The effect, viewed from the street level, is similar to that of a length of only 330 feet of double-storey street, not approximately 500 feet, as stated on page 110 of the Report of the Royal Commission on Cross River Traffic in London. On such a short length, daylight from both ends helps greatly. In looking at Argyle Street, it is, therefore, necessary to imagine what the effect would be if the upper storey extended from Anderston Cross on the west to Glasgow Cross on the east, a distance of 5,000 feet instead of 330 feet.

28. Another example of a modified two-storey street is Kingsway, London. There the additional storey is placed below ground level in the form of a subway for the use of tramways only, the length of the tramway-subway being about three-quarters of a mile. As a much-needed city improvement, its value is beyond criticism. As a contribution to the problem of city local passenger transport, it is negligible.

29. There remains the most serious difficulty, X, crossings on the level—route and junctions. With a two-storey street, the additional street, whether above or below ground, must join the ground-level streets. Fig. 4, Plate I, the Roosevelt

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Road viaduct, gives an idea of the length of the inclined approaches necessary.

30. A good idea of the space inevitably occupied in the ground-level street by the inclined way connecting it with a street on the storey either immediately underneath, or above, is available at Southampton Row, at the northern end of Kingsway. In looking at this, it is necessary to remember that the subway, being for tramways only, has a much steeper gradient than would be permissible for any other form of transport. The encroachment, measuring about 20 feet wide overall, on the main street surface, which measures 60 feet wide from kerb to kerb, is, consequently, there correspondingly short.

31. Connections between a first-storey street and the transverse streets, at ground level, are a still more serious proposition. In the New York proposal, as in the great high-level viaducts, 200 feet high, suggested for London, such transverse connections seem to be omitted. They are, however, contemplated, as shown in Fig. 4, Plate I, for the Chicago proposal. Their provision would mean the entire reconstruction of the transverse streets, with their buildings and other difficulties, which will become apparent in discussing the next suggestion.

32. There was in the "Graphic" of 23rd April this year a picture under the title of "A Vision of To-morrow." It showed how one city street could, apparently, easily cross over another

The aspect of the "Vision" changes when worked out. This has been done in Plate II, Figs. 1 to 5 of which show the results if applied to the crossing of Sauchiehall Street by Newton Street and St. George's Road; and Figs. 6 to 8 if applied at the crossing of Jamaica Street and Argyle Street, Glasgow.

Figs. 1 and 2 show it with the lesser, or north and south, traffic streams carried over the greater streams in Sauchiehall Street.

The length of the approaches required would entail a

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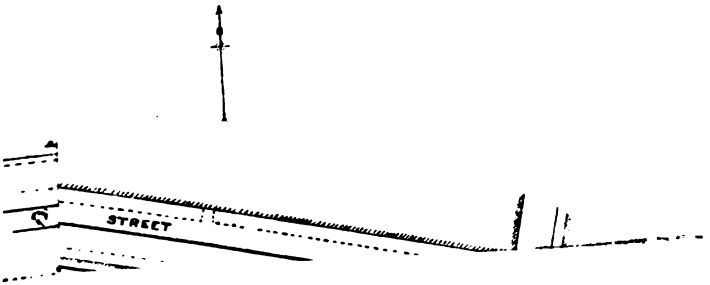
ER.



the exception of a lavatory,

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southern approach blocking Bath Street, and extending over the London and North-Eastern Railway and Elmbank Crescent, the latter of which it would block, into India Street. Figs. 3, 4, and 5 show the less impracticable method, that of carrying the main Sauchiehall Street streams over the lesser, north and south, streams.

The eastern approach could be constructed without blocking any other stream. The western approach, Fig. 4, would prevent traffic, other than pedestrian, crossing Sauchiehall Street from North Street to Woodside Crescent. It would come to the Sauchiehall Street level just clear of, but rather too near its junction with Granville Street. Sauchiehall Street would require to be widened by a breadth of at least 45 feet, Fig. 5, by the taking down and setting back of the buildings on its south side from Elmbank Street at least as far west as Granville Street. The elevation, Fig. 4, shows how it would affect the ground-floor shops throughout its whole length.

Figs. 6, 7, and 8 show the proposal worked out on the Argyle Street-Jamaica Street crossing by carrying the north and south traffic over Argyle Street, the only practicable way in consequence of the railway bridge. The approaches would block the crossing, except by pedestrians, of Union Street and Jamaica Street, Fig. 7, for a length of 130 yards to the north, and of 200 yards to the south, and inconveniently restrict the junctions at Ann Street and Howard Street. The elevation, Fig. 7, similarly shows what the effect would be on the ground-floor shops on the east side. Union Street and Jamaica Street would require to be widened by at least 45 feet, Fig. 8, say, on their western sides. That would mean carrying the western side of the street back to the railway boundary practically throughout, with the consequent elimination of all buildings on the west side of the street.

33. In 1910 I worked out a similar proposal, in full detail, for the crossing of Jamaica Street at the north end of Glasgow Bridge, by crossing under the ground-level street. Figs. 9, 10, and 11 of Plate II show the proposal.

It had the advantage that, with the exception of a lavatory,

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no buildings would require to be interfered with, the Broomielaw and Great Clyde Street being wide enough, reasonably, to stand the encroachment in width of the inclined approaches. These inclined approaches, however, would have extended sufficiently far in both directions to block any extension over the river of Oswald Street or Dixon Street. That was sufficient to condemn the proposal. It would, obviously, have prevented the construction of the King George V Bridge at Oswald Street.

These illustrations on Plates I and II show the great difficulty in the elimination of X, crossings on the level, in the streets of an existing city.

The cost of all street improvements would, as a matter of course, like bridges, be borne by the public, and not, except in so far as they were ratepayers, by the commercial transport concerns who use them.

34. *Railways.* With the exception of the local railway system known as the Underground Group, in London, and possibly one or two other quite minor ones, the railways in this country are those of the main-line railway companies.

The traffic with which these railways have to deal was concisely stated by Mr. J. H. Follows, vice-president of the Executive of the London Midland and Scottish Railway, in a recent paper read before the Institution of Transport at Birmingham.

The relevant quotation is as follows:—

"*Classes of Trains.*

"Except in the case of some suburban lines, all classes of traffic—fast and slow moving—have to be worked over the same line of rails, and to meet these conditions a system of traffic control of a precise and exact character is demanded. The traffic to be worked is divided into the following classes:—Express passenger trains, stopping passenger trains, express freight trains, through mineral and empty wagon trains, stopping freight trains, and local trip services to meet the requirements of collieries and works."

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The area controlled by each of these companies extends roughly from one end of the country to the other, over hundreds of miles of route. The qualified exception, mentioned by Mr. Follows, indicates the first of the consequences which arise from the attempt to superimpose on these main-line companies' lines, intense passenger services over the relatively insignificant lengths on the already most heavily worked portions of their systems. That is, goods traffic must be eliminated.

Doubtless Mr. Follows used the word " suburban " as comprising both suburban passenger transport and city local passenger transport as defined in this paper.

35. *Railways. Suburban Passenger Transport.* Suburban passenger transport illustrates, but in a less acute form, the difficulties presented by city local passenger transport. For the required fast, but stopping, service, electrification is the primary essential. Some good work in this direction has been carried out by main-line railway companies, and has not been confined to the London area. From the evidence given at the South East of London Inquiry, the Southern Railway had, up to October of last year, spent a total of £8,000,000, and then had 213 route miles electrified. They had in contemplation the expenditure of another £5,000,000 in the vicinity of London.

Particulars, without total costs, of the electrification of the Metropolitan Railway, more a suburban than a main line, were given at the North and North East of London Inquiry about a year earlier. A casual reading of these figures might give the impression, quite wrongly, that electrification could be carried out at a cost of from £35,000 to £40,000 per mile.

36. Many other points have to be considered. Terminal and other stations have to be reconstructed to permit of mixed steam and electric working. A sample of the work involved in this can be gathered from a recent paper on the Remodelling of the Charing Cross and Cannon Street Stations on the Southern Railway, read before the Institution of Civil

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Engineers.* The only omission in that paper is any reference to the cost.

Again, the more successful the results of electrification, the more quickly and acutely do the two outstanding difficulties arise, namely:—

W. Insufficient size of channels entailing widening.
X. Elimination of crossings on the level entailing fly-overs.

The cost thus rapidly multiplies.

37. At this stage, the conflict in the requirements of passengers for main-line and for short-distance journeys respectively, materialises. Three examples will suffice, namely:—

1. Where is the electrification to stop? Electrification of long lengths of main lines can hardly be controlled by the needs of the relatively short lengths required for suburban passenger transport, and still less by the relatively quite insignificant lengths required for city local passenger transport.
2. Why should trains be run relatively long distances to pick up short-journey traffic?
3. The short-distance traffic, under city local passenger transport at least, does not require rolling stock of the size of the main-line stock. On the other hand, the main-line company, rightly, does not wish to have more than one wagon, and consequently structure, gauge.

It seems clear, however, that suburban passenger transport, *i.e.*, beyond a radius of ten miles from the centre, nevertheless is the province of the main-line companies. For distances of not less than that length, their large rolling stock is the more suitable.

38. As mentioned under § 8, item 1, railway companies have statutory duties. A housing authority also has at least one statutory duty, namely, to provide houses.

* Vol. 223, pp. 168-190-192.

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In the inquiries referred to, it was suggested that knowledge of the commencement of a housing scheme should be sufficient to cause the railway company, or companies, concerned forthwith to attend to their duty of providing the fast and frequent passenger transport necessary. The next query, "regardless of cost," took the edge off the suggestion. How can it be otherwise under the existing conditions summarised in § 8?

39. *Railways. City Local Passenger Transport.* Within the radius of about ten miles from the centre of the city, the difficulties mentioned under § § 35-38 become greatly intensified. For the fast and frequent service required for city

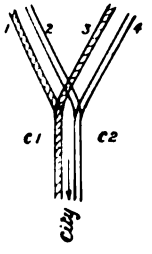

Fig. 3.

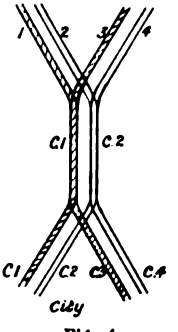

Fig. 4.

local passenger transport during the rush hours, trains must run at intervals not exceeding a few minutes. Mixed steam and electric working, undesirable for suburban passenger transport, is quite impossible for city local passenger transport.

40. From the extreme case, London, it is possible vividly to illustrate how the two main difficulties, W and X, § 17, inevitably arise even on railways solely for city local passenger transport.

Fig. 3 shows the ordinary junction of two double-track routes from the fringes, becoming one double-track route in the city area. This one double-track route, as it continues citywards, has also to deal with its own intense traffic. Obviously under this design the capacity of the route varies inversely with the

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traffic, W trouble. Again, the down-line (3) crosses the up-line (2) on the level, X trouble.

That represented the position, less than five years ago, at the junction of the Hampstead and Highgate Tubes.

Referring now to Fig. 4, over five years ago, at a point about a mile or so citywards of the junction, there was the termination of another local city railway close to, but in no way connected with, the one, but overloaded, double-track route, C.1, C.2. The natural and ordinary method would have been again to divide C.1, C.2 route into two by the ordinary junction

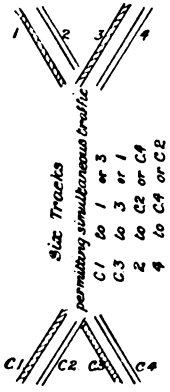

Fig. 5.

indicated at the lower end on Fig. 4. The result would, obviously, have been a bottle-neck, and trouble W for the mile or so of the double-track route between the junctions, with X trouble at both junctions.

That is what would have happened had the City and South London Railway, which then terminated at Euston, been connected in the ordinary manner to the Hampstead-Charing Cross Tube.

Fig. 5 shows the solution adopted. The essence of it is the conversion of V into W, § 17, by the provision of three pairs of tracks, instead of one pair, between the junctions; and the elimination of X by fly-over crossings at the junctions.

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KENNINGTON TUNNELS.

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FIG. 3.

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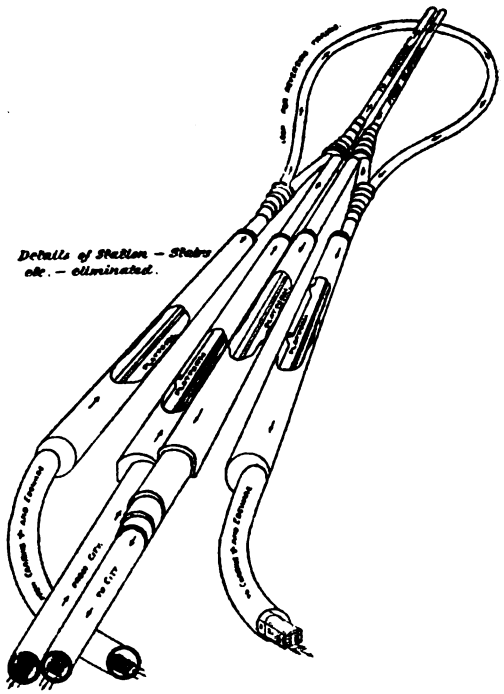

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41. The well-known Camden Town tunnels, opened three years ago, on the two routes approaching the city from the fringes on the north, show how these two outstanding difficulties, W and X, have been got rid of in practice.

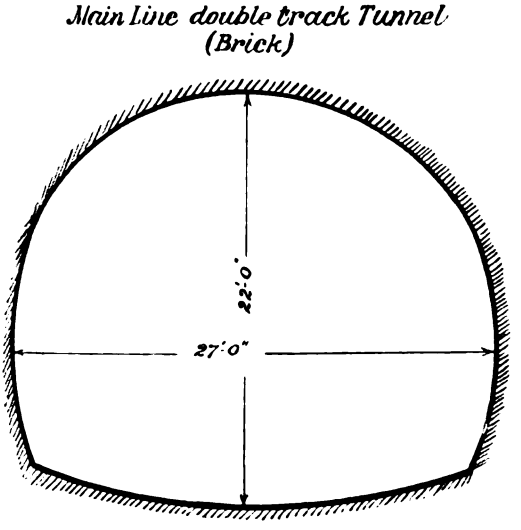

Fig. 6.

By kind permission of the Right Hon. Lord Ashfield and Mr. H. H. Dalrymple-Hay, the engineer for the works, I have been permitted to reproduce in Figs. 1 and 2, Plate III, illustrations showing these tunnels. The arrangement keeps the capacity of the routes constant—a very different matter from varying inversely to their duties.

The ideal, of course, would be to have more routes in the city area. Thus the capacity would vary directly with the duty. This ideal also has been given effect to quite recently in London. The point is Kennington, in the city, on the new one double-track route from Morden, on the fringes in the south-west. There the Morden one double-track route is doubled by joining the southern ends of the two city routes already men-

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tioned as converging on the north at their other end at Camden Town.

A turning loop and other facilities enable a proportion of trains from the two city routes to have their outward terminal at Kennington. The other difficulty, X, is eliminated by fly-over crossings.

By the same kind permission, the actual arrangements at Kennington are shown in Fig. 3, Plate III.

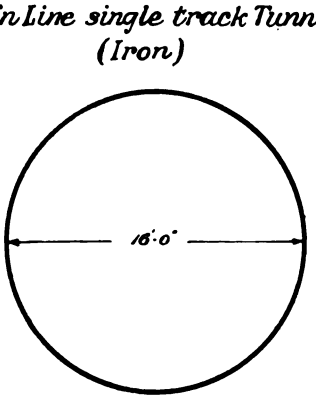

Fig. 7.

42. Reverting now to the question of local *versus* main-line railways, § 37, a fourth point has to be considered.

Fig. 6 shows the ordinary form of the double-track British main-line tunnel. From my own experience, I do not consider that such a double-track railway tunnel would now be constructed under cities in this country. The method which would be used would be that of two single-track tunnels constructed in iron tunnel.

The size of each would be not less than 16 feet in diameter, Fig. 7, as in that of the Great Northern and City and other recent tunnels in London, and somewhat less than the diameter of the single-track Mound tunnels in Edinburgh. If, however, the line were constructed as a city local transport railway only, the size could be considerably reduced.

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Fig. 8, 11 feet 8¼ inches in internal diameter, shows the standard size for the London tubes. The actual size which should be adopted for any given city local passenger transport railway would, of course, be a matter for adjustment between the tunnel, the rolling stock, and the traffic man. Among other things, the recent developments in the multiple-unit system of rolling stock require careful consideration. Eleven feet in diameter might, perhaps, be sufficient; or 12 feet might be found desirable. In any event, the diameter would be considerably less than that required for main-line rolling stock.

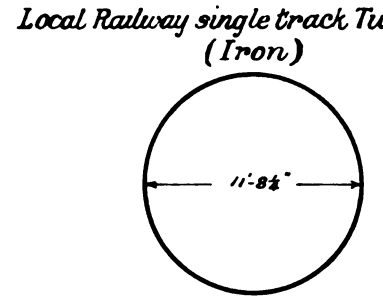

Fig. 8.

It is clear from the above that the cost of a railway constructed in tunnel, if of tube size, *i.e.*, for city local passenger transport only, would be very much less than that of a railway—or a widening of an existing railway—to carry main-line rolling stock. The size necessary for main-line rolling stock would also obviously make arrangements such as those at Camden Town and Kennington, Plate III, very difficult, if not, in most cases, impossible.

43. A word is now desirable with reference to the Paris Metropolitan and Nord-Sud system of railways for city local passenger transport. In Paris the strata, although somewhat "hard to get," are, in my opinion, the easiest strata possible to work in; I had experience of the same strata in 1917 in what, in the army, were known as the "back areas." For

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that and possibly other reasons, Paris does still construct double-track tunnels.

For the Paris local railway system, these double-track tunnels are considerably smaller than the double-track tunnels required for their main-line railways. They are 5 feet less in height and about 4 feet less in width than the British main-line tunnel shown in Fig. 6. Paris experience, although in the easiest possible strata, consequently confirms the statement in § 42.

Other foreign examples could be quoted, but these would refer to systems which I have not personally studied on the spot.

44. As regards layout, the accepted principle now is that of shuttle working, as distinct from circle working. The original ideas lay to circle working. The change in ideas can be illustrated by both Paris and London experience. By kind permission of L'Inspecteur Général des Ponts et Chaussées, Inspecteur Général des Services techniques du Métropolitain et du port de Paris, and of the Right Hon Lord Ashfield, skeleton maps of Paris and London local railway systems respectively have been shown in Figs. 1 and 2, Plate IV.

The history of these systems is, incidentally, an interesting illustration of national characteristics. Prior to 1898, when the construction of the first lines in Paris was authorised, the whole scheme, hardly so extensive as that which has now materialised, was envisaged.

In London, on the contrary, there was not (there is not now, in fact, so far as is publicly known) any such scheme; like Topsy, it grew.

Both methods, in the one case more correctly lack of method, have their advantages and disadvantages. Space, however, does not permit of dealing with more than the question of circle *v.* shuttle working.

In Paris the scheme, as originally propounded, consisted essentially of one circle, passing as a circle through the Place de l'Etoile and somewhat west of the Porte de Vincennes, with

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FIG. 2.

LONDON.

LOCAL RAILWAYS.

kind permission of The Rt. Hon. Lord Ashfield of and H.H. Dalrymple-Hay, Esq., M. Inst. C.E.

For Tube stock only .... ——
" Main Line stock .... - - -

these lengths have since transferr

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nd somewhat west of the Porte de Vincennes, with

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certain subsidiary circles and also shuttle lines. During construction the circle idea was abandoned. The original main circle was cut into two semi-circles, with terminal hoops on each, at or near the Place de l'Etoile and west of the Porte de Vincennes, as shown. As a consequence—certain very small circles, really large turning loops, excepted—the Paris system has always been worked on the shuttle principle.

In London, on the contrary, circles, *e.g.*, that known as the inner circle, were constructed on the original steam-driven Metropolitan Railway and Metropolitan District Railway. These circles, consequently, still remain, Fig. 2, Plate IV. On the other hand, all the tube lines have been constructed and worked on the shuttle principle.

45. Space does not permit more than a passing reference to constructional engineering points. Strata vary in different cities. London has the advantage of the London clay. Against this, it has a number of other disadvantages which do not exist in other cities.

It is difficult to conceive conditions, large river crossings provisionally reserved, which cannot be effectively and economically handled by modern methods in iron tunnel, especially of a size not greater than 12 feet in diameter. The skill which has now been acquired in the use of the hooded shield, first introduced by Mr. Dalrymple-Hay, in conjunction with air pressure, is perhaps the most important factor.

Glasgow, underneath which I have constructed many miles of tunnel, is no stranger to this factor. Eighteen years and more ago the hooded shield, in conjunction with air pressure, was used there in three cases so successfully as to attract no attention. One case was a tunnel, over one mile in length, at an unusually shallow depth for tunnelling, which extended from Gorbals Cross to the General Terminus at St. James' Street. The other two were some rather smaller works, but more tricky, one in the same vicinity, and the other on the north side, near Finnieston Street.

The three well-known Glasgow contractors who executed these lengths have since transferred themselves and their

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staffs to London. There a main outlet for their energies is, in one case, London tube tunnelling, and, in another, London large main-sewer tunnels.

The difficulty, somewhat peculiar to Glasgow, would be one of a quite different character, namely, possible tapping of old underground workings which are full of water. The hooded shield and air pressure are no use for that. On a very short length, the somewhat catastrophic results, as regards cost only, of such an occurrence in Darnley Street, Glasgow, are recorded on page 196 of Vol. CLXXIX (Session 1911-12) of the Proceedings of the Institution of Civil Engineers.

Such occurrences, however, although their exact locality cannot be foreseen, would necessarily be few, and limited to very short lengths. Consequently, as in the case of the scheme referred to, they would, provided the estimates had not been unduly optimistic, have no visible effect on the cost of the whole scheme.

46. Invaluable lessons on other points are available from the actual, in varying degrees hard-earned, experience of Paris and London. Among these are the adherence to the standard rail gauge; the avoidance of unduly sharp curves; the easing of the diameter of the tunnel on curves below a certain radius; the provision of underground cross-overs and of underground sidings; the proper location, with handy access, of running-shop lyes for nightly examination of cars and of main depots for thorough overhaul, etc.; and, of course, the construction of the tunnels true to line and level. Unfortunately, in the case of the only, small and now old, example in Glasgow, all these lessons are still too obvious.

Conclusion.

47. Recapitulating, as starting data, for a thorough study of the question, the following points seem clear:—

1. The City Housing Problem cannot be solved in accordance with modern requirements—not to mention playing fields—without a fast and frequent system of city local passenger transport.

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2. The required fast and frequent city local passenger transport cannot be found on the city streets. If anyone doubts this, the most effective, although hardly justifiable, method of proving it is to continue the endeavours to provide it on the streets.
3. The only thorough solution seems to be what is known as a tube service.
4. The provision of a tube service, although distinctly expensive, seems considerably less so than that of any other method.

48. The question of cost must be faced. For a tube service, provided in tunnel including all accessories, the cost of the usual double-track route runs from £850,000 to £1,000,000 per mile. The suggestion of any overhead figure below £750,000 per mile is unjustifiable. So far as the city area proper, *i.e.*, the area already built on, is concerned, tunnelling cannot be avoided.

If, however, § 12, the provision of the tube service precedes the building of the houses, it can, generally, be provided, as on the Golders-Green-Hendon-Edgware extension, by a special railway constructed on the surface. The cost per route mile can then be divided by the factor six, bringing it to round about £150,000 per mile, all accessories, rolling stock, etc., included.

This desirable reduction might be obtained by simply earmarking, prior to the erection of buildings, the necessary strip of ground, and thus deferring the construction of the line until building had proceeded so far that a certain revenue would immediately be forthcoming. This is a point which, with all respect to them, town planners appear to have entirely overlooked.

49. It is obviously impossible to provide anything in the nature of a network of tubes. As is already clear, tube routes, with the exception possibly of certain duplications within the city (see § 41), should be on lines radiating from the centre.

One such line, extending from the centre in both directions

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to most likely building areas, would be a good start. It would effectively serve, without assistance, a strip about half-a-mile broad on each side of the railway, or one mile total breadth. With the assistance of road passenger transport—commercial public service, private car or cycles, etc.—on the fringes and at the terminations of the lines, it would effectively serve a much greater area.

Road commercial passenger transport concerns can operate comparatively freely on the fringes.

A tube service, however, would have increased difficulty in paying its way if confined merely to entering the fringes, say, to a point about four miles from the centre of the city. That length is admittedly the length within which the difficulties to fast road passenger transport are at their maximum. It is, unfortunately, the length within which the cost of the construction of a tube is also at its maximum.

As buildings extend outwards, so will the radius beyond which fast road passenger transport can work freely inevitably be pushed out. It is desirable, therefore, that the first termini should be nearer five miles than four miles from the centre of the city, and that their ultimate extension to, say, about ten miles from the centre should be envisaged. When the extension of buildings justifies the tube service extending ten miles from the centre, the soundest economical length for such a service would be reached. It would also be that giving the most satisfactory service for daily travellers.

The overall speed, stops included, of a tube is about 20 miles per hour. That of road passenger services is, in the inner area, what the traffic conditions, and, on the fringes, what the safety of the public generally will permit, say, overall not more than, if as much as, half that of a tube service.

50. The main points which are within, or strictly relevant to, the province of the engineer have been touched on. There are, unfortunately, many other, and much greater, difficulties. Under present conditions, some of the immediate consequences awaiting those who have ventured, at a large expenditure of money, to provide a tube service would be:—

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The local authorities, for the convenience of whose constituents the line was provided, would at once assess the "new hereditament."

Among other purposes, they would use the products of the assessment as a "handsome contribution" to the upkeep of the roads whereby the "competitors" of the tube service "would filch" from the tube service "the traffic" created by it.

An acknowledgment for the quoted words is due to Mr. I. B. Pritchard, who, when appearing for the East London Railway Company, incidentally not a tube service, before the South East London Inquiry on 8th November of last year, put these two points neatly.

The value of the land would go up, possibly, as has been the case elsewhere, to an extent which, by checking the building of houses, would check the creation of the traffic to meet which the tube service had been provided.

The public, thinking that it is possible both to have and to eat their cake, would encourage the road services on fine days, and complain about the inadequate tube service on wet or foggy days.

It is unnecessary to go outwith Glasgow for examples of the lack of encouragement, and worse, awaiting would-be promoters of a public service such as a tube service. Shortsighted views, tinged perhaps with municipal politics, and undue competition are the causes.

51. It is reasonably possible that, coupled with the development of city housing, not to mention playing fields, there would be enough money in city passenger transport and city local passenger transport to develop and use therein all suitable forms of passenger transport. Each form would, of course, require to be restricted, so far as is reasonably possible, to the purposes which it is best fitted to perform. The desideratum is that all, irrespective of municipal boundaries, shall work into each other. Some form of control, not more than absolutely

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necessary, including pooling of the receipts, would also be required.

One word "co-ordination" is frequently advanced as the simple solution. Unfortunately, more than words is required. From this point of view, the position might well be given up as hopeless.

52. Fortunately in the past, large schemes which appeared equally hopeless when first suggested have materialised. A brief mention of one may lead to a point of view with a less hopeless outlook. The time was over 80 years ago. The problem was the water supply of Glasgow, then wholly obtained by pumping in Glasgow from the Clyde.

In 1840 extensions, coupled with amalgamation, of the various existing water works had been completed. The total capital expenditure on these works exceeded £400,000. The revolution in water supply, consequent on dissatisfaction with the Clyde water, nevertheless became imminent. All kinds of schemes, many shortsighted, began to be discussed.

In 1845 the requirements were 9½ million gallons per day. In that year—simultaneously with the starting of the Gorbals scheme, which still supplies about half that quantity—someone dared to mention Loch Katrine. Such a suggestion at that time was a very bold one, equally if not more daring than the facing now of city local passenger transport. It, further, was a pioneer scheme; more than can be said now for a tube service for city local passenger transport. Its success was immediate, and its lead was followed by Manchester, Liverpool, Birmingham, and other cities.

The Transactions of this Institution* contain a complete history of the water supply of Glasgow, starting with Harley's Willowbank pumps and water carts, and terminating with the duplication, over 30 years ago now, of the Loch Katrine Water Scheme.

An outstanding feature has been the ordered, apparently even

* Papers by James M. Gale: vol. vii (1863); vol. xii (1869); vol. xxvi (1883); vol. xxxviii (1895). See also Marwick, Glasgow: The Water Supply of the City, etc., 1901.

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leisurely, manner in which that scheme has been steadily developed, always well in advance of requirements. As a result, the Loch Katrine Water Works, sufficient when inaugurated in 1859 for a daily supply of 20 million gallons, are to-day sufficient for a daily supply of 75 million gallons. Further, when the relatively small work entailed in bringing the Endrick and Blane Valley syphons up to the capacity of the remainder of the new aqueduct is put in hands, they will be sufficient for a daily supply of 110 million gallons. That would appear ample for the demands of 30 years hence, at least a century after 1859.

Considered and prolonged thinking on sound lines is obviously the first essential. This paper is presented in the hope that it will give the necessary impetus to initiate that.

53. The foregoing was written in June of this year. In the middle of October, a further and important London Traffic Report came out. Two relevant excerpts therefrom are appended.

Attention is drawn to the words "extreme urgency" in the concluding excerpt. That is a most undesirable state of affairs. Its repetition elsewhere can only be avoided by thinking ahead.

Excerpts from "Report" (dated 27th July, 1927) "of the London and Home Counties Traffic Advisory Committee to the Minister of Transport, giving Particulars of a Scheme for the Co-ordination of Passenger Transport Facilities in the London Traffic Area."

"10. DEVELOPMENT.—The recent Inquiries by the London and Home Counties Traffic Advisory Committee into the transport needs of various sectors of London have shown that there is an insistent and justifiable demand for additional railway facilities which cannot be met in full because certain of the Railway Companies contend that their financial position, under existing conditions, is not such as would enable them to raise the necessary capital.

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"Given unified management and efficient operation of the various passenger transport agencies in the London Traffic Area, there is little doubt that the consequent elimination of the present wasteful competition would result in sufficient revenue being obtained from the operation of the several undertakings at the present level of fares as to leave, after meeting all legitimate claims and obligations, a margin available to attract fresh capital sufficient to provide for a programme of steady and continuous development of the traffic facilities of the area.

"12. . . . . In conclusion, the Committee desire to emphasise their view that this matter is one of extreme urgency, as they feel convinced that no substantial improvement of the travelling facilities in Greater London can be effected until some such scheme as is outlined in this Report can be made effective."

Since the paper was read, I have received numerous suggestions that it is incomplete without a reference to the existing railways within the area of city local transport in Glasgow. Plate V has, consequently, been prepared. On it the railways and railway stations have been shown boldly in black, with the subway railway in dotted black.

At a first glance there seems to be no lack of railway lines. To any who know the real situation, as the members of this Institution well do, the map is, however, largely a record of wasted effort so far as city local passenger transport is concerned. It is clear that the equipment and facilities offered by these lines are not up to modern requirements in city local passenger transport. One adequate reason for this arrested development in the equipment of these lines has been stated in § 8 of the paper; others have been indicated in § 50.

Perhaps the Plate will help the citizens of Glasgow, as a preliminary to thinking ahead, to glance backwards and seriously consider whether they are not the real parties who are primarily responsible for this arrested development. The date from which past actions should be reviewed is, I suggest, the middle

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railway company could be induced to electrify that li

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tions should be reviewed is, I suggest, the middle

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eighties, when the Glasgow City and District Railway was opened, and thereafter, and more particularly, the early nineties, when the Glasgow Central Railway, the Lanarkshire and Dumbartonshire Railway, and other lines, indicated on Plate V, were opened for traffic.

Discussion.

Mr. JAMES DALRYMPLE: Although I am not now actively engaged in the traffic business, I cannot very well escape from it, and my interest in local passenger transport is as keen as ever. Like Mr. Easton, I suppose I have seen almost all the tubes in existence, not only in this country but in Europe and North America. At Buenos Aires there is a very fine tube, one of the few successful tubes in existence so far as finances are concerned. Shortly after the twopenny tube was started in London, the matter was considered in Glasgow. I went carefully into the finances of the London organisation, but came to the conclusion that there was very little hope of a similar tube being constructed here. A private concern would not consider the question, and the municipality could not attempt such an undertaking, because they could not draw sufficient money to pay the interest on the capital and to meet the sinking fund charges.

The citizens of Glasgow do not really yet know what congestion is. What does exist is confined to a very small area and to a few streets in the centre of the city. In many other cities there is enormous congestion spread over a very large area. Mr. Easton points out that the motor traffic has doubled between 1921 and 1926, and yet, compared with other cities, such traffic in Glasgow is small. If, however, we are to have the same experience in the future as many other cities have had already, it will be necessary to look more particularly into the question of tubes for Glasgow. A railway runs from east to west in Glasgow under the whole of Argyle Street, a railway which is doing very little, and I have often wondered if the railway company could be induced to electrify that line, which

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Mr. James Dalrymple.

operates in a splendid traffic territory, and if it were carried out what effect it would have on local passenger traffic. Before undertaking the construction of tubes at a cost of possibly a million pounds a mile, it would be better to have an object lesson which would cost very much less.

Fifty-five years ago the municipality of Glasgow extended its tramway system beyond the municipal boundary, and about 25 years ago the tramways were electrified, and the whole surrounding area covered with tramway lines communicating with the centre of the city. Some people say the Corporation made a great mistake at that time. They did nothing of the kind. I am thoroughly convinced that nobody in this room will survive to see the day when the tramcar will be dispensed with, and I believe that if tubes existed to-day they would not put a single vehicle off the streets To a great extent the tubes would carry the people who live outside the three-mile radius of which Mr. Easton speaks; they would not carry many within that area because, with a bus or tramcar passing their door, for the few minutes longer it might take to make the journey, people would travel by the car in preference to walking to a tube station. I should like to know whether Mr. Easton has calculated how many miles of tube would satisfy the districts surrounding Glasgow, and what capital expenditure would be involved.

I recently had occasion to report on a similar traffic question in a city which is growing very rapidly. During my few months' stay buildings were being erected by the hundred, and people were streaming into the city by the thousand. The problem was how to convey the people several miles to and from their houses on the outskirts. The streets are narrow, and quite unsuitable for ordinary traffic. I suggested something like what Mr. Easton proposes, namely, that in laying out the outskirts of the city a right-of-way should be secured before the buildings are erected, as it would be absolutely necessary that some arrangement of either tube or overhead railway be made to meet the traffic. Possibly, in the years to come,

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Mr. James Dalrymple.

if Glasgow grows, something of that kind may require to be done, but in the meantime we are not ready for it.

Mr. THOMAS SOMERS: I know that Mr. Easton has devoted a great deal of time to the consideration of traffic distribution in cities in general, and in Glasgow in particular. I also know that Mr. Easton has, shall I say, a weakness towards the tube as the solution for all traffic problems, and his paper should stimulate thought on the question of how the city's development is to be met in regard to transport problems. To my mind, the whole matter appears to be bound up with finance. As Mr. Easton points out, tubes are very expensive to construct through a city that is presently developing. The question naturally arises whether the carrying capacity of such tubes, when constructed, will recoup the promoters for their capital expenditure. Given an attractive proposition, private enterprise will not be lacking to meet the want. If the proposition be not commercially attractive, the difficulty then would appear to be how to finance such a scheme. The alternative appears to lie in somebody having to provide the transport, with the deficit on working being met by some other party. The ratepayers within the city of Glasgow, particularly at the present time, would not view with any cheerful attitude the idea of having any further addition to their rates to meet such a deficit as might occur.

Within its present municipal boundaries, Glasgow is covered by a radius of about five miles. Mr. Easton refers to a recent Town Planning Conference which dealt with the original planning of the Clyde valley area. There are adjacent to Glasgow and outwith that five miles' radius, considerable numbers of small burghs and certain developing county areas—some of these have been described as the dormitories of Glasgow—districts such as Giffnock and Bearsden. I have not yet heard that the means of transport to and from these districts are considered unduly inadequate, or that the railways have been unable to cope with the numbers wishing to get to these dis-

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Mr. Thomas Somers.
tricts. If the railway companies have been lacking in any way, private enterprise, in the shape of motor buses, has done much to remove that disability.

Mr. Dalrymple quite properly points out that in Glasgow, congestion, as it is generally understood, is practically non-existent, and what does exist is confined to a very small area in the centre of the city. Even that congestion is capable of being dealt with without going to the extreme measure of constructing tube railways. As Mr. Easton suggests, a great deal can be done by providing parallel routes. Glasgow, bisected as it is by the river from east to west, lends itself very well, so far as the east-west traffic is concerned, to such a scheme, and if certain classes of traffic could be diverted to routes parallel to those now used, certain congested points would be considerably relieved. While by so doing present unimportant crossings might be made a little more important, I do not anticipate that they would become so congested as to retard unduly the progress of through traffic, at least for many years to come.

The river is a difficulty in the traffic from north to south. It is significant that no bridge west of Glasgow Bridge has been erected until the King George V Bridge, which will be opened for traffic early next year; that is the first bridge west of the Glasgow Bridge that has been erected in Glasgow over many centuries, and considering that the whole trend of the development of Glasgow has been westward, it is surprising that the erection of such a bridge has been so long delayed. It was only last year that Glasgow considered it desirable and necessary to obtain powers for the construction of a bridge west of the present Glasgow Bridge or the bridges generally about the centre of the city. It does not appear to me to be necessary, and the far-seeing motorist does not consider it necessary that he must enter or leave Glasgow by a route passing exactly through the centre of the city. At present there are three good bridges leading to the south, and the motorist is becoming more and more alive to the fact that two of these bridges are not used to the extent that they might be. Accordingly he is

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Mr. Thomas Somers.

making a slight detour, thereby gaining in time what he loses in mileage.

At the present time, while Glasgow is growing on its fringes, there is, with the increasing use of mechanically-propelled vehicles, a sufficient provision for getting people to and from the city in a reasonably comfortable manner. To assist further in this direction, the railway companies might do something in connection with the electrification of their existing suburban lines, while some system of connecting links between the existing lines within the city, at its fringes, might materially facilitate the distribution of passenger traffic.

There is something to be said for Mr. Easton's plea that, in connection with town planning, some reservation might be made, so that when a method of transport other than road is required the reservation would be available. I do not know that Mr. Easton is quite correct in assuming that town-planning engineers have overlooked that aspect of the problem, but one of the great difficulties in a town-planning scheme is to know exactly where to place the reservations. It is very difficult to ask a landlord for a strip of land, and to tell him that some day there may be a railway on it. It may materially affect the layout of that particular estate, and lead to some very complicated questions, particularly in assessing compensation on what after all is a somewhat problematical line that may never be made. While an attempt may be made to anticipate development on certain lines, it does not always follow that the anticipations are realised.

Mr. Easton suggests that the solution of the housing problem is to get the transport there first and the houses will follow, and he cites an example of what has been taking place in London and district. To apply that case to what is, after all, a small city like Glasgow is hardly a fair parallel. There are many districts surrounding Glasgow that appear eminently suitable for the building of houses, but investigation shows them to be impossible of development for many years to come. On the other hand, districts which looked as if they would be

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Mr. Thomas Somers.
the last to be developed are, strange to say, being taken over and developed by private enterprise.

Mr. JOHN DALLAS, D.L.: In considering a city like Glasgow, the average man is too apt to take the development during the past 20 years as an indication of what the development will be in the next 20 years. Mr. Easton takes a far broader view, and fully realises that, since the introduction of mechanically-propelled vehicles, we must look further ahead. About 60 years ago there were discussions about Jamaica Street corner, and proposals were put forward to clear away some property. At that time members of the Corporation would not even consider the purchase price that was asked, and it was merely infinitesimal compared to the price which would be demanded to-day. Consequently, the whole inquiry resulted in the cutting off of one small corner in that area. Recently the Corporation were quite glad to pay a considerable sum of money to purchase a block of property at the corner of Union Street and Argyle Street, and it is very questionable if it will serve any purpose at all.

I quite agree with Mr. Dalrymple and Mr. Somers that, from the point of view of finance, it is utterly impossible to consider the tube question at present. If private enterprise cannot be persuaded to take the matter up, the Corporation cannot face the problem, as the ratepayers are already overburdened. But surely there are some ways of relieving traffic congestion in Glasgow. Whatever might be done in areas like Giffnock and Bearsden, the real problem of congestion concerns a small area in the centre of the city. Mr. Somers' suggestion to use parallel streets for special traffic points to some kind of solution, but a proposition to construct a tube at a cost of a million pounds per mile is out of the question. Surely a method might be conceived wherby, with the expenditure of such a sum, more satisfactory results could be obtained than with a short tube one mile in length.

To a certain extent the congestion in some streets might be relieved by diverting part of the traffic to other thorough-

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fares. In some of the large cities in America night traffic is organised for the shifting of goods, in order to relieve the congestion caused by commercial vehicles during the day. In Manchester there is an organised parcel traffic carrying about 40,000 parcels per week, and earning an income of £36,000 a year. If something of that kind could be developed in conjunction with our tramway system, a considerable amount of congestion would disappear in Glasgow.

Mr. Easton suggests overhead railways at certain points as a means of easing traffic, and that would possibly involve a rearrangement of the tramway tracks in certain areas. After all, the main point is not the consideration of the Corporation tramways, and if the congestion can be relieved by stopping the cars before they reach the centre of the city, although a slight loss may be incurred, I think it is worth while considering.

Mr. J. B. L. Meek: Mr. Easton has selected a subject that is of considerable interest at the present time, as many cities are faced with the problem of traffic congestion, either in an acute form or one that bids fair to become acute in the near future. He also appears to be on sound lines in recommending tube railways as being the ultimate solution of the problem, both from a traffic congestion point of view and as a means of rapid transport of the population of a large city from their homes to their work. The price of land near the centre of a city is generally far too high to permit of house building, even were it desirable for people to live in the centre of a city. Therefore, the habit of people living at considerable distances from their work is bound to increase in the future.

Looking at the question entirely as a business proposition, and excepting London, which is a case entirely by itself, there are hardly any cities to-day with sufficient population to warrant the laying down of a system of tube railways being a financial success. The constructional costs of tube railways are high, and the fares would have to be low to compete with bus and tram fares; therefore the lines would have to be used almost to their capacity to show a return on the capital expended.

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Mr. J. B. L. Meek.

Assuming that a great deal of the traffic of the future will have to go under ground, is the present time opportune to construct a system of tube railways that will not pay for some years to come? Does either the congestion in the streets or the present travelling facilities justify it? The answer at the present time appears to be in the negative, for the following reasons:—

The traffic congestion problem is at the present time confined to an area of about half-a-mile radius in the centre of a city, and most cities, where the congestion problem is pressing, have trams in the centre of the city, dividing otherwise good roads into two narrow roads, where the speed of the traffic is regulated by the slowest-moving vehicle.

Outside the congested area there is, at the present time, room in the streets, and generally good alternative routes, to enable both ordinary traffic and trams to be accommodated without congestion.

A great amount of capital has been expended in equipping tramways, and this capital should be utilised to the full as long as it is possible to run trams without causing serious delay to other traffic.

There are hardly any cities to-day where tube railways would be a paying proposition.

It is, however, time that steps were taken gradually to alter the incidence of the traffic with a view to future developments, and this should be done with as little waste of money as possible. To begin with, trams should be entirely excluded from the congested central area of a city, as it will generally be found that the carriageways are wide enough for normal traffic for many years to come when they are free from the inflexible tramcar. As the congested area is generally comparatively small, many people would walk from the tram termini at the boundary of the congested area to their work, and buses could be provided to accommodate those who wished to be conveyed across the central area. As buses are much more mobile than trams, they do not cause anything like the same congestion. This arrangement would obviate street

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widening just where such work is most expensive, and cause little, if any, inconvenience to the population.

Outside the central area, let the trams still run and do the useful work they are now doing. When, however, extensive renewals are required on any route, the question of whether or not the time had arrived to substitute a tube railway for the tramway with any chance of financial success should be very carefully considered. If this plan were followed, most of the present congestion would disappear, the expense of constructing new streets or widening old ones would be saved, the capital already sunk in tramways would be given as long a life as possible, the change from surface travel to underground travel would be gradual, and the necessity of constructing tubes long before they would pay would be avoided.

Mr. A. J. Fleming, LL.B.: Summarising, as it does, the problem of transport to-day, and visualising the future with a clear view, Mr. Easton's paper represents a remarkably able and thoughtful contribution to what is admittedly one of the most acute problems of the day, not only in our country, but in other civilised states. I am not competent to discuss the engineering problems which Mr. Easton has presented and illustrated by plans in the course of his paper, but I propose to refer to some general considerations, which must enter into any attempt to solve the problem.

In the first place, I would like to recall very briefly how transport, which originated on the roads, passed to the railways, and has now come back very largely to the roads. In pre-railway days the only means of locomotion in the country, with the exception of a few canals, was by the King's highway, and in the Glasgow newspapers of 100 years ago you will see advertised the places and times of departure and arrival of the old Stage Coaches. During the first few years in which railways were spreading their network systems all over the country, the Stage Coaches made a brave attempt to carry on, but by the time (in the early forties of last century) the railways had become firmly established as a means of quick and safe

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Mr. A. J. Fleming, LL.B.
transport, the old Stage Coaches, at any rate along the principal roads, had died a natural death.

Although the railway systems of this country were built up entirely by private enterprise and capital, yet the State, by the Railway Act of 1844, encouraged the flow of private capital into the railways by an Act of that year, which made provision for the State acquiring future railways on the basis of 25 years' purchase of the annual divisible profits estimated on the average of the three preceding years; and it is interesting to note, in view of the very small return now being paid on railway capital, that the Act assumed that the average rate of profits so ascertained would not be less than 10 per cent., and provided that, where it was less, an additional amount of purchase money should be paid to the company for the prospective value of the undertaking, to be ascertained in case of difference by arbitration. The Act was the outcome of proposals submitted to the House of Commons by a Select Committee, from whose report the following is a quotation:—"The Committee doubt whether the establishment of railways in this country does not afford a more remarkable instance than can be cited from any analogous subject matter, of immense and certain and almost uniform benefit to the public, combined with a very moderate standard of average remuneration to the projectors."

Some 1,350 millions of private capital was spent in building the railway systems of this country, and, although the railway companies had to expend vast sums in paying for the lands through which their lines were built, in constructing their lines and stations, and in Parliamentary expenses in obtaining the Acts of Parliament under which their various lines were constructed, it is remarkable that the characteristic of British railway organisation has been the tendency to put out new capital at a rate faster than has been warranted by the actual increase in earnings. To the public benefit, although not always to that of their shareholders, up till a few years before the war, the railway companies certainly acted on the principle that competition is the soul of trade, and they were

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constantly vying with one another for new worlds to conquer. By this progressive policy, they have been a very potent factor in developing the trade, commerce, and agriculture of this country.

The result, therefore, of railway development, up to the commencement of the war, was that the railways carried practically the whole transport of the country, both passenger and goods, and that the passage along the roads of transport was negligible, except probably in the city of London, and, in fact, the roads, paved with macadam, were not suited to bear heavy commercial transport. Since the war the increase in the manufacture of motor vehicles, both private and commercial, has come so rapidly, with the result of transferring back to the roads in increasing amounts traffic formerly carried by the railways, that the problem under discussion had become acute before it was realised that the problem was there at all. Even now, while the motor manufacturers in this country are engaged in an orgy of turning out motor cars at so many thousands a week, and we are threatened with a new Ford raid of the same kind from America, the Minister of Transport has made no attempt to grapple with the problem, except in regard to the London traffic, and contents himself with the maintenance of the existing roads, and the provision of a few new arterial roads built at a capital expenditure out of all proportion to their value as any solution of the problem.

The position now is that there are two main and competitive channels of transport. (1) The railways recently reorganised by Act of Parliament into four amalgamated companies, with charging powers fixed by a Rates Tribunal to produce the nett revenue of the year 1913 and no more, with allowance of interest on capital expended since that year, with statutory machinery for regulating hours, working conditions, and wages of their employees, and with obligations to the public to provide adequate goods and passenger service; and (2) road mechanical transport companies and individuals not organised, not regulated or limited by statute except *nominally* in regard to speed, able to charge such rates and pay such wages as they please,

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and with no obligation imposed on them as to providing services further than certain local restrictions. Further, as pointed out by Mr. Easton, the railways have not only to maintain their track and stations, but have, in addition, to pay all local rates, including road rates upon a valuation of their lines and stations, while road transport pays nothing for the use of the roads which it uses as its track and for its stations, except a licence duty which does not, through the Road Fund, wholly pay for even the damage done to the roads by its traffic. Then again, this enormous passing of transport to the roads has completely changed their character. Instead of being highways for the use of all the King's subjects, they are now maintained at vast cost practically as nothing else but a smooth and convenient track for mechanical transport. Mr. Wallace Fairweather, chairman of the Upper District Committee of Renfrewshire, recently stated that a census of road traffic showed that 99 per cent. of the traffic on the Kilmarnock Road, and at least 95 per cent. on other roads, was motor traffic. It is the fact that road rates have increased since pre-war by 300 per cent., calculated after allowing for the post-war increased cost of maintaining the roads on a pre-war standard of maintenance. This means that road transport is a subsidised industry, subsidised by the ratepayers. The ratepayers' position is that the more they are driven off the roads by road transport, the more they have to pay for their upkeep, while the position of the railways is still more unenviable, in that the more traffic they lose to the roads, the more they have to pay for their upkeep. This state of matters is entirely contrary to the original principle of the upkeep of the roads, which was that traffic, other than foot traffic, using the roads paid for their maintenance, payment being levied through a system of tolls collected at toll-bars and toll-houses erected by the old Road Trustees. By the Roads and Bridges Act of 1878 tolls were abolished, and the maintenance and repair of the roads was laid upon the owners and occupiers of lands and heritages within each district, who were to be assessed therefor.

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Subsequent legislation has paved the way for the state of the roads to-day. Up till 1896 no locomotive could be driven along the roads in the open country at a greater speed than four miles an hour, or through any town or village at a greater speed than two miles an hour, and there were very strict regulations as to the manner of working locomotives on the roads, and their size and weight, etc., but by the operation of an Act in that year and subsequent statutes, these restrictions have practically disappeared, and, though the regulations as to speed still exist, they are not enforced. The result is that motor traffic passes along the roads as it pleases, heavy transport generally insisting on having the crown of the road, and there are more accidents on the roads in one day than there are on the railways of the Kingdom in a year.

What is the solution to this problem of modern transport in all its phases? It appears to me that the first step, before launching out into any new schemes of expenditure, either on roads or railways, is to co-ordinate the two forms of transport, and before that step is reached, and as a preliminary, to regulate by Act of Parliament the use of the roads for commercial purposes by mechanical transport. To begin with, commercial transport on the roads must cease to be a subsidised industry. As a step towards this, I would suggest that the contribution to maintenance by the ratepayers should be a fixed standard rate per pound of assessable rental, and that the standard rate to be fixed should be that levied by each local authority for the year 1919. This would mean that the increased cost of maintaining the roads to their present standard would fall upon the real users through the Road Fund. Then I would suggest, as the next step, legislation to provide for the amalgamation or co-ordination of all commercial road transport, and for that purpose I adopt the definition of commercial transport given in Mr. Easton's paper. The principles for such amalgamation or co-ordination may be found in the Railways Act of 1921 and/or the recent report of the London and Home Counties Traffic Advisory Committee to the Minister of Transport. The next and final step would be some form of

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co-ordination of rail and road transport, and the principles upon which the Electricity Supply Act, 1926, is based might be called in aid. It seems to me that a necessary preliminary step towards that final co-ordination would be to give the railway companies powers, which they do not at present possess, to run road transport, including power to acquire existing road transport undertakings. As probably the largest ratepayers in the country, they are fairly entitled in common justice to obtain these powers.

Co-ordination between road and rail would pave the way for development of the schemes for the future which Mr. Easton has so ably set forth in his paper, but it must be kept in view that at the present time, while the roads are congested by motor transport, the railway companies are in a position to handle efficiently a far greater volume of traffic, both passenger and goods, than they are, owing to the competition of the roads, at present doing. Further, the need of the hour is to keep down all capital expenditure that is not likely to be immediately remunerative.

Mr. Henry Mattinson: Mr. Easton's paper is, in the main, a survey of the various expedients adopted in many towns to deal with the problem. My personal view is that the subject is approached from an entirely wrong angle by most communities, and instead of dealing with, and therefore encouraging, the more intensive traffic in the busy areas, the approach should be that of analysing the characteristics of the traffic and endeavouring to arrange its points of origin and destination away from congested areas. I am well aware that no authority has power to do this to-day, but consider that authorities should be so empowered, so that occupations involving extensive traffic, *i.e.*, warehouses, works, etc., could be definitely excluded from certain areas, and these areas reserved for personal services such as offices, showrooms, etc. In other words, I suggest a policy of prevention rather than cure, although I definitely recognise the magnitude of the difficulties involved.

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Mr. R. Killin.

Mr. R. KILLIN: I have read Mr. Easton's paper with great interest, and while I can hardly subscribe to his statement that the whole question of transport in this country is in a chaotic condition, I can agree with him up to a point. Transport itself was never better organised than it is to-day, but the conditions governing it have been forced into a chaotic state by reason of the rapid advance in motor transport since the war, and the lack of adequate government or municipal control, and I presume it is to this Mr. Easton applies the term chaotic.

As he states later on in his paper, there are, generally speaking, two forms of transport—road and railway. The conditions pertaining to railway transport are, broadly speaking, the same now as before the war, but those pertaining to road transport have altered very materially. Before the war the speed restrictions on motor vehicles laid down by the law were observed in a reasonable way, and if not observed, were dealt with by the police. Motor buses and motor lorries kept fairly near their legal speed, but after the war, and particularly round about 1922, the roads were flooded with motor buses, each striving with the other in wild competition. The result was that speed restrictions were thrown to the wind, and to-day motor buses can be seen flying along our roads at speeds varying from 25 to 45 miles per hour. So numerous are they that the police cannot restrain them or keep them within the law, and it can be truly said that they have taken illegal possession of the roads by simply overwhelming the powers that be, and smothering the law by weight of numbers. They are not subject to the conditions under which railways and tramways work, nor are they subject to the same inspections or inquiries before and after accident, and the speed at which they travel not only makes it dangerous to walk on the road, but in winter the foot passenger is splashed with mud and in summer smothered with dust, while the conditions of our roads are such that the pedestrian has almost entirely lost his right to their use.

These are the features which seem to have forced Mr.

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Mr. R. Killin.
Easton to the opinion that more, and different, transport is necessary for the needs of the city, but if carefully examined it will be found that the need of more transport is more apparent than real.

Mr. Easton's scheme for city local passenger transport resolves itself broadly into a scheme for transporting passengers from the business area of the city to the residential area in the suburbs. He has taken for his purpose the business area as of three miles' radius from the centre of the city, and the suburbs as extending to ten miles from the centre. His idea is that electric tube railways should be run from the centre of the city to the suburbs, but it is not quite clear who he has in mind to provide these tubes. Such a scheme as this could be undertaken either by government, municipal, or private enterprise. It is hardly likely that the government would face such a scheme for Glasgow, when in the background there are many other cities that could equally demand schemes of the same nature, and more especially as the tendency of the government at the present time does not seem to lie in the direction of nationalisation of the railways. The Glasgow Corporation is not likely to face the cost of such a scheme, keeping in view the transport they already possess in the shape of tramways and subway. This leaves private enterprise as being the only source from which such a scheme could receive financial support, and provokes reflection as to what private enterprise has already done in this direction.

If a map of Glasgow be examined, it will be seen that railways belonging to private companies radiate from the centre of the city for distances of ten miles in any direction, and for much further in some directions. Mr. Easton seems to think that the fact that these railways carry freight as well as passenger traffic is against an intensive passenger traffic being conveyed on these routes, even with electrification, and he quotes Mr. J. H. Follows as being apparently in support of his opinion. In this connection, however, I would point out that Mr. Follows' paper was given on "traffic control," that

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is, a regulation of traffic (all kinds) as performed from a given centre; that is, a headquarters equipped with telephones, etc., to all necessary points, and amongst other duties the control would time out freight trains so as not to interfere with the running of passenger trains. I venture to suggest, therefore, that Mr. Easton has rather misinterpreted Mr. Follows' remarks.

The existing lines are capable of handling a very much heavier passenger traffic during the rush hours, even if they continue to be worked by steam, but if electrified, they could handle very much more traffic. It is, therefore, a matter of fair comment why new tube lines should be proposed, instead of full advantage being taken of the existing lines, even if it were necessary to widen or extend them. In proof of this, it may be pointed out that, at the rush hours at present, the existing railways are not carrying up to their full capacity, large numbers of passengers having been diverted from the railways to motor buses by cheaper fares, etc., and even the motor buses at the rush hours are not by any means full, so that more of these buses are running on the roads than are warranted by the traffic. The police have no adequate means of regulating the numbers of buses on the streets, their speed, or what stances or streets shall be used. Yet, as Mr. Easton points out, these vehicles do not pay local rates unless where they have their garages, much to the detriment of other forms of transport.

The remedy would appear to be a firm and proper control of road traffic regulated by properly constituted bye-laws, in order to safeguard the public on the streets, and also the user of such concerns; inspections and inquiries by the Ministry of Transport as to the fitness of the vehicles, and inquiries into each accident where injury arises. The ratepayer should obtain relief from an unjustifiable burden, by local rates being levied on these bus concerns in the same way as they are levied on tramways and railways. This would prevent road transport from running at the expense of the ratepayer, and the relief granted to the railway companies would admit of

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Mr. R. Killin.
their costs being reduced, and enable them to compete on a fair footing with bus concerns.

Mr. Easton, however, may quite fairly say that this does not supply the need for more and quicker transport from the centre of the city to the suburbs, in view of the growth of population he envisages. He indicates that the solution of the problem can only be obtained by electrification, but the great barrier to the electrification of railways hitherto has been the cost of erecting installations for the production of the current wherewith to run the railways. This is now being produced by large companies such as the Clyde Valley, etc., which makes it easier for railway companies to buy electricity than to generate it themselves, and thus brings the electrification of railways nearer every day. The electrification of railways may, sooner or later, become an easy accomplishment, financially and economically, and the advance of electrical distribution which is foreshadowed by the Electricity Bill, and which is even now going on, is bringing the problem nearer to its solution, and I venture to say it will arrive in good time to meet the position forecast by Mr. Easton.

Mr. JAMES ANDREW: Mr. Easton says 50 years is not too much to look ahead. It is a very long time, much longer relatively, viewed from the standpoint of to-day, than it was viewed from the standpoint of 30 years ago. Who would have thought 25 years ago that the railway companies would to-day be faced with such competition by road transport? Who can foretell what may be the fate of the roads 50 years hence? It appears to me that, in these quick-change days, "looking ahead" may be overdone. We live in an age just on the fringe of airways transport development, which may revolutionise the transport branch of human activity in no less a degree than motor road transport has done. Consequently, I say take a reasonably broad view of the subject, and march with the times, or be just a little ahead, but not too much.

Mr. Easton advocates the building of tubes. These seem to be part and parcel of London life now, but I am not sure

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Mr. James Andrew.

that city requirements generally call for such expensive works. The tendency for the travelling public is to take the vehicle that keeps to the highway. To such an extent has this developed that Glasgow is suffering from acute congestion. There are two ways of dealing with this congestion. Firstly, to look upon it as an inevitable and permanent feature of city transport, and provide means, at very great cost, to meet it. With the passing of time, the congestion may not remain stationary, but may rather increase, so that the means provided may sooner or later appear inadequate. Secondly, to regard the congestion as a curable trouble. Mr. Easton indicates that he would apply the first remedy, and I grant that his treatment would be successful; but if he has not already done so, it would be interesting and instructive to have his views on the second method.

As I have already stated, the public will use the transport that keeps to the highways. Therefore, establish more traffic routes. The first essential in a city cut in two by a river is bridges or subways. Given these, the congestion will be relieved. I consider the time must come when certain classes of traffic will be required to use certain routes. Further, at present the streets are "to let," as it were, for a good eight or ten hours out of the 24. Surely during these hours the streets might be utilised for part of the transport that causes congestion during the day. My plea is to explore every possible way of taking advantage to the full of present facilities, amplifying these where necessary, as indicated above.

Mr. W. W. Marriner (Vice-President): The model here exhibited shows a proposal made by Sir Alfred Yarrow in 1924 to relieve the traffic congestion at some of the street crossings in London. He offered to erect, at his own expense and at any point where the authorities wished, an overhead bridge like that shown by the model. He proposed that the bridge should remain in position for two years, and if it proved a success the authorities should pay for it, but if it proved a failure he would demolish and remove it as his own expense. The first

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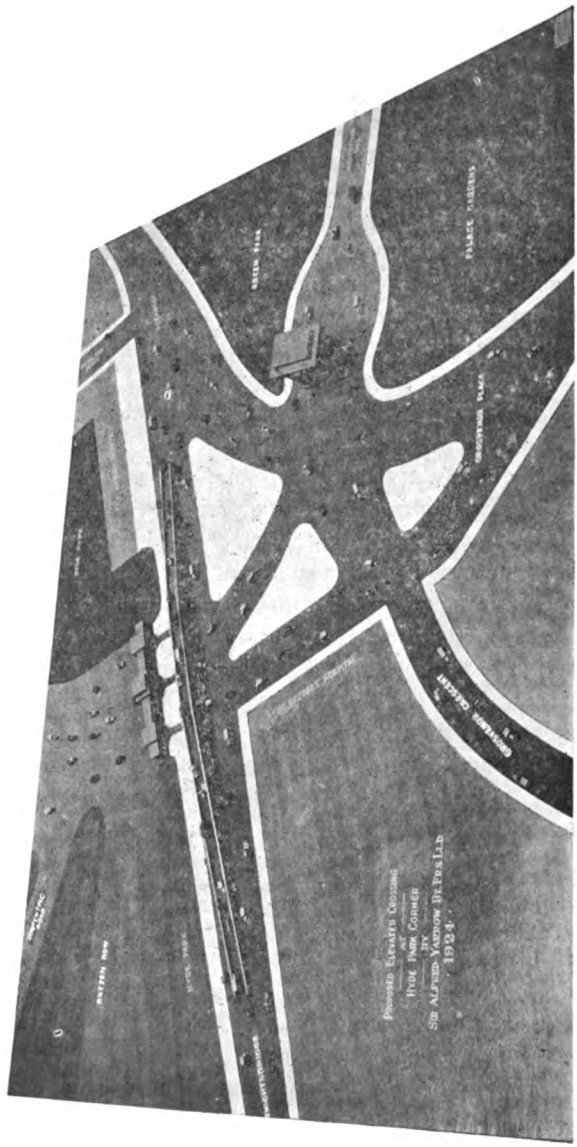

Fig. 9.

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Mr. W. W. Marriner.

suggestion was for the bridge to be at the crossing of Regent Street and Oxford Street, but an insuperable difficulty there was the question of compensation, which was soon raised by the shopkeepers in that district. It was then proposed to put the overhead bridge at Hyde Park Corner as shown in Fig. 9, and the scheme was generally approved by the Minister of Transport and the authorities, but, unfortunately, that part of London is now under the jurisdiction of at least five authorities, and it was impossible to arrange to carry out the scheme.

As a user of the roads, I do not quite agree with Mr. Easton's statement that transport is in a state of chaos; that is rather overstating the case. It is merely that people desire to get about very much more quickly than they used to do. I drive through Glasgow at all times of the day, and very often when men are leaving work between five and half-past six o'clock, and I am quite sure that with a car it is possible to travel much more quickly, even at the rush hours, than anyone could with a horse conveyance during a slack period, say, on a Sunday morning at half-past nine.

As to the means of transport, it strikes me that it is a question of what the people are prepared to pay for quick transport. It was officially stated in London that the tramways did not pay at all, the underground railways just held their own, and the buses paid, and that appears to be the rule everywhere. In some American cities, buses have completely displaced tramcars. I believe that in New York it is proposed that the suburban traffic shall be carried by buses, and not by subway or tramcar. The Glasgow buses have perhaps not yet reached the final stage of their development, but it is apparent that people prefer to travel by bus. The mobility of the bus makes it, in many ways, a very convenient form of transport, because the passengers are more likely to be taken close to their destination, and do not have to walk too and from a station and climb stairs as in the case of a tube railway. I suggest, therefore, that the future development of our traffic will be on the road.

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Mr. W. W. Marriner.

A thoroughfare of greater width than the Great Western Road in Glasgow is of no advantage whatever. It has been found that very wide roads on the outskirts of London are positively unsafe, because people think if they have plenty of room they can wander all over the road, while if the road is of moderate width they keep within certain limits. As we cannot do without horses for a long time yet, it is suggested that the sides of the roads be cobbled, so that heavy horse-traffic will keep to the left-hand side, and leave the centre for the faster-moving motor traffic.

Mr. A. Leitch, B.Sc.: It is quite correct to say that roads are now made at the public expense; this is, however, a post-war phase. New roads used to be made by estate proprietors in accordance with the specification approved by the local authority, and then taken over as public streets by the latter. Naturally, in order to reduce maintenance costs, local authorities wished to have as good roads as they could get, but their standard became far higher than is required for feuing purposes. It did not matter much to the estate proprietor what kind of road he made or what it cost, so long as the local authorities took it over as a public street. He simply recovered the price at a later date from his feuar, who had to pay practically whatever rate per foot of frontage the proprietor charged. This was never a satisfactory arrangement, but worked fairly well until 1911, when the Land Valuation Act was passed, and estate proprietors practically ceased to make roads.

When the Government schemes for the so-called working-class houses began, it was obvious that if roads were made to local authorities' requirements, they would be much too expensive, and, for housing schemes, roads which do not comply with the said requirements, are made. If a private estate owner makes roads similar to housing scheme roads, he cannot have them taken over as public streets. Such roads as are now being made are for Government or municipal housing schemes and unemployment relief works, and until local authorities recognise that feuars are not entitled to bear the

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whole expense of forming main roads, existing conditions are likely to continue.

For railways, the cost of obtaining statutory powers was in some cases more than the cost of construction of the works, and should be counted in with the other charges under item 2, § 8 of the paper. The railway companies were granted their powers because it was in the interest of the public service, and it is well occasionally to remind them of the fact. The said powers do not appear to have been intended to enable them to prevent other philanthropic people from doing a public service. The Acts also imposed on the companies legal disabilities, which are now more irksome and onerous than could have been foreseen. The country needs railways, but that new railways will be built under existing conditions appears to be unlikely.

The housing problem may be solved by private enterprise whenever the facilities for providing roads indicated above are arranged, and if the existing antiquated and expensive legal machinery for the sale and transfer of property is scrapped. The expense of transferring a house at a price of, say, £600, to which buyer and seller have agreed, is about £15, of which £6 is stamp duty and the remainder legal fees. This is almost a Gilbertian state of affairs, but the legal people seem unable to have it changed. Meantime private enterprise has little encouragement to undertake the provision of roads, houses, or railways, and much public money is being wasted. It would certainly be well to make provision for transport facilities where houses are to be built, and this may be done under the Town Planning Act. The demand for transport to the city from any particular area does not arise until the houses are occupied.

As regards the street crossing difficulty, Fig. 10 shows an example worked out for Argyle Street and Great Clyde Street by my partner, Mr. R. H. Sharpe. Beginning on Jamaica Bridge, it was proposed to raise the car lines, with a gradient of 1 in 20, high enough to cross over Great Clyde Street traffic, continue at a high level along Jamaica Street to Argyle

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Mr. A. Leitch, B.Sc.

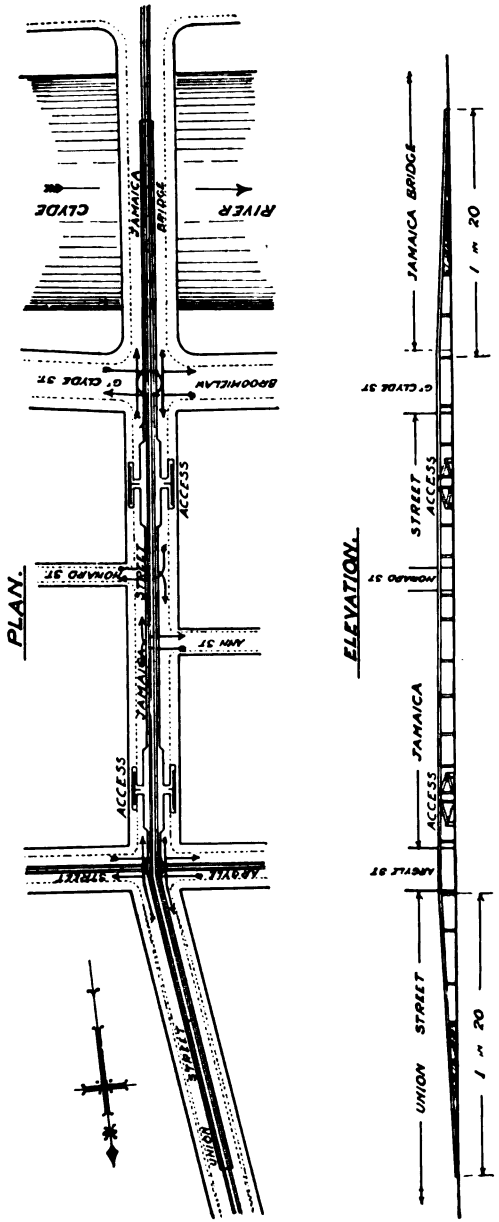

Fig. 10.

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Street, and grade down at 1 in 20 to about half-way up Union Street. The plan was submitted to the Corporation in 1922, but it was decided to wait until the King George V Bridge at Oswald Street was completed, and the effect of it on congestion observed. Through the good offices of Mr. Marriner, the plan was submitted to Sir Alfred Yarrow in 1924 in order to ascertain if he would make the same offer to Glasgow which he had made to the London authorities, namely, to erect the structure himself and to remove it if the city fathers so decided. Sir Alfred considered that the Glasgow congestion did not warrant the outlay.

Such congestion as there is in Argyle Street seems to be unnecessary, as tramcars coming from Dumbarton Road might be turned up Hope Street, and go west again *via* Bothwell Street, but probably our traffic superintendents have some reasons for the existing procedure. Similar methods might, with apparent advantage, be adopted with other car routes, and the congestion at Argyle Street corner—the only part of the city where it is worth mentioning—be eliminated entirely. The existing suburban railways might be developed further if the companies were encouraged to do this. Electrification may help, but according to the newspapers Sir Josiah Stamp is doubtful if the necessary outlay would justify itself.

The useful radius for tramcars appears to be about three or four miles from the centre of the city, and for buses perhaps about ten miles, but for speed, comfort, cheapness, safety, and regularity, nothing can compete with the railways. If anyone knows where there are better or cheaper railway services than in the vicinity of Glasgow, I should like to visit the place.

What the cost of tube railways may be in 50 years' time is somewhat difficult to predict, but now the sum of one million pounds per mile seems a pretty high estimate. I agree with Mr. Easton that the time for tubes is not yet, but, nevertheless, we are entitled to look ahead and try to foresee what provision should be made for future developments. Many schemes have been proposed, and some have been tried and

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Mr. A. Leitch, B.Sc.

proved unsuccessful. No doubt many more may have a similar fate, but by continually trying, the best will eventually be evolved. There is need for railways, motor buses, and electric trams now. Each has its sphere of useful operation, and the more efficient facilities for traffic are, the more easily will trade be carried on and increased, to the mutual advantage of all parties.

Mr. JOHN BRYCE: Mr. Easton's paper appears at the psychological moment when the subject of transport is receiving attention on all sides. Mr. Easton deals with it as an engineer, and advocates a solution of the problem with his well-known enthusiasm. I am responsible for the position and planning of the extensive housing schemes of Glasgow, and consequently, the subject is bristling with personal interest, for I recognise that when the houses, roads, and sewers are completed, the schemes themselves are by no means completed until fast and frequent transport is provided. Mr. Easton quotes London as an example, but Glasgow is not London, and never can be. It will be many a year before our population is two millions, whereas the population of Greater London at present will be about ten millions—a nation in itself.

Speed in these days is a kind of fetish. To have everything fast and frequent may be ideal, but it is not politic. Mr. Easton seems to expect that at the mid-day rush hour a large proportion of the occupiers of houses built under the new schemes would want to go home for lunch. I do not believe that for a moment. It would be more convenient for the majority to go to the restaurants with which Glasgow is so well provided, and it is a moot point whether the cost of transport and the loss of time would be economic. In any case, it would be a "rush," and I am afraid that, while some would start it, they would not keep it up. So, assuming that better provision were made for fast and frequent transport, it would be for the majority a morning and evening run. Whether that would pay can be roughly estimated; I question it very

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Mr. John Bryce.

much. Still, I believe with Mr. Easton that we should look 50 years ahead, and it is hard to prognosticate what will happen in that time. If, however, a scheme like that aimed at by Mr. Easton were carried out and it did not pay for the first ten years, it might pay handsomely after that period.

There is no doubt that the population of Glasgow is going "outwards," and our schemes, with a possible population of 15,000 at Riddrie and Carntyne, 20,000 at Mosspark, Craigton, and Cardonald, 24,000 at Knightswood, 8,000 at Ruchill, Hawthorn Street, and Balmore, and 5,000 at Balornock, Springburn, not to speak of 10,000 at King's Park district and the schemes which are being provided for the future elsewhere, have to be provided with fast and frequent transport; for a large number of the residents in these districts earn their livelihood in the centre and business part of the city. However, I am inclined to think that the existing railways, widened and extended at some parts, with frequent stations, and, of course, electrified, would meet the situation for a long time, at any rate until Glasgow became more like London.

I do not agree with Mr. Easton that tubes or railways ought to precede housing schemes. The demand at the moment is for houses and more houses; we cannot supply enough of them, and cannot afford to wait too long for them. Surely, with the many radiating lines from the centre of Glasgow belonging to the railway companies, and the exercise of engineering skill by the staffs of these companies, provision might be made to meet the requirements of citizens for many a year to come. When the bus services are added to this, and also our splendid tramway service, which has recently been accelerated in speed, I consider that the occupants of houses in these districts will be well supplied with the necessary transport.

Economy is the watchword at the present time, and any scheme that will tend to minimise expenditure is to be furthered. On this point, I cannot understand Mr. Easton when at the beginning of his paper he extols economy, and at the end he advises the Corporation or some other authority to undertake an expenditure of about five million pounds as a

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Mr. John Bryce.

beginning. However, I may be a little lacking in imagination, and have to recognise that there is such a thing as false economy. Any scheme that can be proved to be useful for the majority of the citizens, and can be advanced as an ultimate profitable undertaking, should be encouraged and promoted by every means in our power.

Mr. M. KISSANE: Mr. Easton's treatment of the subject is mainly from the engineering standpoint, and it is impossible for me to discuss matters of that kind. His four conclusions, however, touch on questions of a more general character, and it may not be amiss to make a few observations on them, more especially in their application to Manchester, the only city, apart from London, with which I am sufficiently familiar for this purpose. I believe, however, that the conditions in Manchester are fairly typical of those in most provincial cities in this country.

With Mr. Easton's first conclusion everyone will agree; probably with his second also. It would hardly be too much to say that in several provincial cities industrial development is checked by street congestion. This is certainly true of Manchester, where the growing commercial traffic to and from the docks is hampered and made dearer by the delay to vehicles passing through the city area. It is an urgent necessity to take public passenger traffic off the streets. That the only thorough solution is a tube service, is an assertion which is supported by nothing else in Mr. Easton's paper. A survey of the existing railway facilities in Manchester and the adjoining area, which are shown on Plate VI, seems on the contrary to indicate that the easiest solution is the electrification of existing surface railways, and that the key is in the hands of the railway companies.

There are two more or less complete circles already in being, somewhat resembling a figure 8, with a common sector from A to B. The northern circle approximately surrounds the city area, and is less than three miles in diameter in any direction. The southern circle surrounds the built-up resi-

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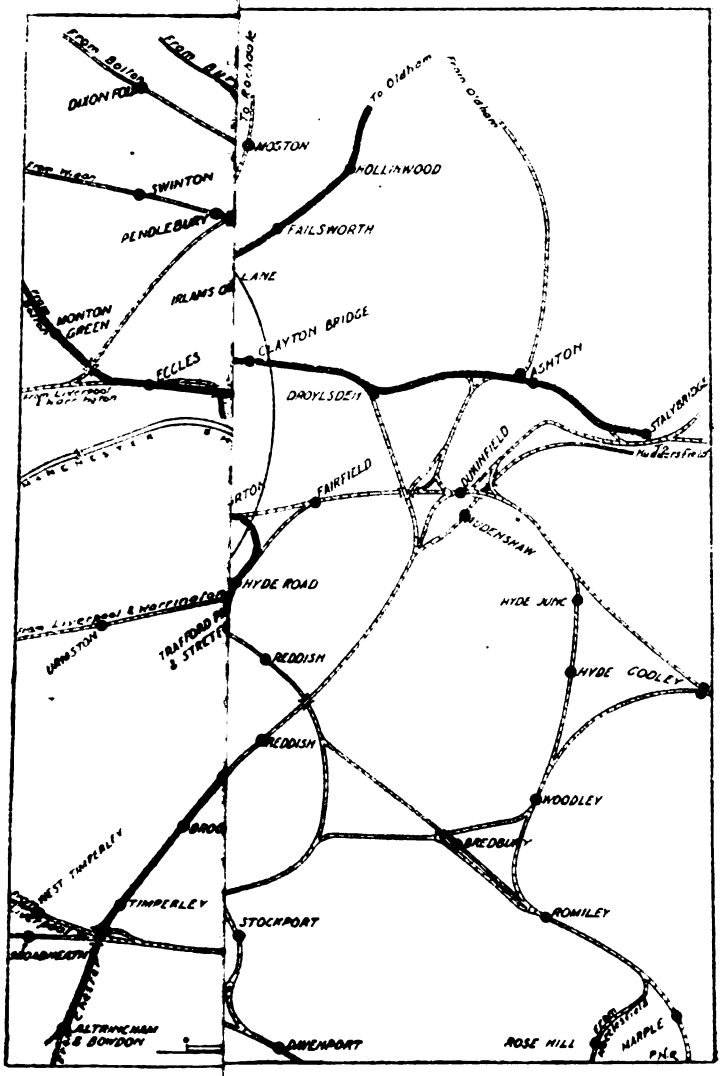

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dential area, and provides a frontier line from which spurs could be projected if necessary to the areas further south, which are ripe for development. The southern circle is less than five miles in diameter in any direction, and could if desired be split up into two or more segments. In addition, there are through communications for shuttle services between the satellite towns, passing through the centre or fringe of the city; between Bolton and Eccles on the north-west and west, and Oldham, Rochdale, and Ashton, and Stalybridge on the north-east and east; between Eccles and Stockport on the south-east; between Altrincham (with extensions to Warrington and Knutsford) on the south-west, and Oldham, Rochdale, Ashton, and Stalybridge; in all cases with ideal distances for economical operation of electric services, and passing through local and suburban areas ripe for development. It might prove necessary to widen or reconstruct the section between A and B, which is for the most part carried on a viaduct, but there appear to be no engineering difficulties in the way. Fly-over crossings at a few points would probably be advantageous. All the railways reaching Manchester are now in the hands of two companies, and this fact should facilitate the solution.

It can hardly be doubted that this would be a cheaper solution than tubes, and it seems a pity to divert public attention to the idea of tubes, which are not a commercial proposition except where intensive development can be counted on. The present trend of vital statistics in the northern cities does not encourage the view that tubes could be provided by private enterprise as in London, and the municipal cities faced with the problem of the possible supercession of their tramways sooner or later by electric train services or buses, or both, will hesitate to embark on the risky and costly experiment of tubes. Tubes have been talked of in Manchester for a quarter of a century, but are no nearer realisation. That possibly accounts for the extraordinary fact that the only railway so far electrified is the line to Bury. Let the public concentrate on what is within its reach. It is interesting to note that

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Mr. M. Kissane.
a commercial scheme put forward as far back as 1902 was based on a system of tubes resembling the figure 8 already referred to.

Mr. R. D. BROWN: With the exception of the London area, high-speed electric tubes, however much they might be desired, must, under present conditions at any rate, remain in the realm of the unattainable. No doubt Mr. Easton had this in mind when he stated at the outset that the present was no time for large capital expenditure. For the immediate future, therefore, all energies must be devoted to the utmost possible development and improvement of existing tracks, vehicles, and stations, on both roads and railways.

As an indication of one only of the very many ways in which improvement is possible, the following excerpt from an Engineer's report on the proposed Manchester Tube Railways, dated 1902, is illuminating:—

> "The materials and fittings of the stations should be of the very best, artistic in design, inviting in character, and capable of being kept clean. The Glasgow Subway Stations are ugly and dirty looking, and consequently repelling; they are, moreover, difficult to find, resembling, in many cases, 'hovels.'"

This is strong language, but it calls to mind the lines:—

> O wad some Pow'r the giftie gie us
> To see oursels as others see us!
> It wad frae monie a blunder free us
> An' foolish notion.

The Glasgow Central Underground Station is a case in point where the traveller is repelled by the sulphurous atmosphere, and where "waiting" rooms occupy valuable space on platforms, etc. Improvements of this sort, however, will only touch the fringe of the subject. The lines of attack are indicated by three very important points which Mr. Easton

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Mr. R. D. Brown.

brings out clearly in the paper, and with regard to them there can be no dispute whatever. These are:—

a. Insufficient width of transport channels, which he calls W;

b. The check to speed and frequency due to level crossings, which he appropriately labels X;

and, possibly the most important of all—

c. The necessity for sound and considered thinking well ahead of requirements.

The first and second are obviously basic facts, which, if they are not faced boldly beforehand, will take their revenge in due course.

Mr. William Burnside (Member): Mr. Easton's paper deals with the passenger transport from the city to an area included between radii of three and ten miles from the centre. In Glasgow this traffic is imposed to a very great extent on the city transport within the three-mile radius, and interferes with it; and one of the main problems is to separate these. I think the inner circle demarcation is too large, because it embraces many areas, such as Riddrie, Rutherglen, Cathcart, and Pollokshaws, which cannot be considered as having city traffic characteristics. Of course, the limits are chosen somewhat arbitrarily.

Of the two factors affecting city traffic—width of streets and crossings—the latter is by far the more important. Glasgow main streets are not exceptionally narrow for their duties, and their capacity can be increased by speeding up the traffic. Speeding-up, again, reacts on the crossings. At present the crossing difficulty seems insolvable. Roundabouts and flying-crossings are possible but costly remedies, and have their own disadvantages. I think that immediate relief could be had by better regulation. For example, east and west progression along Argyle Street from, say, Glassford to Oswald Streets, is almost sluggish. Why? Are point-police the last word in

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Mr. William Burnside.
traffic control? Should cars and other vehicles be allowed to traverse our worst crossing—at Union Street—diagonally? Is it not possible to synchronise movements at adjacent crossings? Parallel roads have been suggested as a relief, but these have not always proved successful. Pedestrians are gregarious, and I think traffic on the whole is conservative in its routes. I heard the late Sir Thomas Mason say once, that when Bothwell Street was formed as a bye-pass, those who speculated on ground alongside made a mistake, because the result was disappointing.

It is suggested also that railway lines should be laid out ahead of building, in order to localise and direct transport. More than one line radiating from Glasgow, if not built originally with this object in view, fulfils it now, and such lines have not been conspicuously successful in determining building sites and attracting passengers. The Burnside and Kirkhill line may be taken as an example. Mr. Easton favours tubes as a means of sorting out and separating city and city local traffic. He may be right. But the whole subject is so full of perplexities, arising from physical features, conflicting interests, divided control, and other causes, that his proposal for the creation of a competent authority to study, examine, recommend, and ultimately direct improvements, must receive serious consideration. It seems to me that the first step to be taken by such an authority would be to arrange for the electrification and otherwise developing of the L.M.S. underground line. The arrested development of this line and others was due to the tramways; it is now the tramways' turn to suffer. The consideration of these would be part of the larger problem.

Mr. J. W. Beaumont: The question of the fuller use of existing lines of railway within the congested area is a very important one, and although the ultimate solution is almost certainly electrification, conversion to such a system would be a costly matter, and it does not appear probable that it will be adopted for some time to come.

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Mr. J. W. Beaumont.

A new type of railway vehicle has recently been put into operation in the neighbourhood of Glasgow. It is known as the Sentinel-Cammell rail coach, and consists of a light coach combined with a steam power unit sufficiently powerful to propel it at speeds up to 40 miles per hour. It thus provides a means of giving the same frequent, rapid, and inexpensive service on the railways that has been the chief reason for the success of the petrol-driven vehicle on the road. The seating capacity of the latter does not, as a rule, exceed 32, and the operating costs, including fair allowance for maintenance and amortisation, cannot be less than 1s. per mile. The Sentinel-Cammell vehicle seats from 50 to 60 passengers, and can, if necessary, carry many more standing, while its total operating cost is approximately 9d. per mile, so that it seems reasonable to suppose that it will give the railway companies an additional means not only of meeting the severe competition which has arisen on the roads in recent years, but of increasing the general facilities for bringing passengers into the city.

A number of these vehicles may be seen at any time running between Airdrie and Newhouse, between Motherwell, Holytown, and Morningside, and on services in other parts of Scotland.

Mr. J. Cowan: In my opinion, the very great cost of tubes, particularly in or near the centre of the city, is sufficient to put them out of the count. The idea of sterilising the ground in connection with town planning along the lines of proposed future tubes—mentioned in the discussion—is not practicable. The period of sterilisation must of necessity be absolutely indefinite. For many reasons, the proposed tubes might never become actual entities. In the meantime the areas on either side of the lines of the proposed tubes would have been throttled in their development, and perhaps partly thrown into disuse, as of course sewers, gas, and water mains, etc., would have to be designed so as to suit the future tubes, and the expense of so constructing them might be prohibitive. This question of expense is, after all, the vital factor. In any event, the construction cost of £150,000 per mile of tube in

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Mr. J. Cowan.

open country mentioned in the paper, including for equipment, is, I am afraid, far too optimistic, in view of the cost of dealing with the numerous roads and public services which would be interfered with.

London cannot be considered a parallel case to Glasgow. The populations are very different in numbers, and the material in which the London tubes are driven is very much more suitable from a "cost" point of view than anything near the Clyde, and that for a long distance east and west of the city.

The ideal for Glasgow and district is to encourage the growth of independent towns with their own industry, or industries, able to exist without help from, or the necessity of being near, Glasgow, and this ideal is quite possible of realisation so long as the sites chosen have good railway communications, reasonably close proximity to coalfields and the sea, and, above all, good trunk road facilities. What is wanted is decentralisation and not centralisation, both from an economic and a health point of view. As regards Glasgow itself, much could be done by improved regulation of the lines and classes of traffic, more cross-river bridges, the electrification of railways for short distances outwith the city, and the improvement of the subway. The congestion of traffic, which, after all, is very local and very temporary, might then be greatly and permanently lessened.

Mr. Easton: I have to express my most cordial thanks to all those who have, at so much trouble to themselves, contributed their views.

The problem is admittedly a difficult and complicated one. Consequently, neither adequate information nor time for a profitable discussion are meantime available. The views contributed, however, all confirm what is obviously the whole point of my paper, namely, the need for considered thinking ahead. These views will make the whole proceedings a most valuable and, I hope, permanent record. My closing remarks, therefore, will not be any attempt to reply; but rather an endeavour

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Mr. W. C. Easton, B.Sc.

to emphasise the primary and essential points which require to be grasped thoroughly, prior to the considered and prolonged thinking necessary.

I most heartily agree with Mr. Killin that the primary essential should be an endeavour to make the most of the existing railway lines. In view of past experience in Glasgow and the present situation, it is fitting that such a suggestion should come only from a railway company's official. Consequently, I thank Mr. Killin most cordially for having made it.

A glance backwards, starting from the commencement of last century, will give a relevant historical review. Clelland's "Annals of Glasgow," published in 1816, contain, in Vol. I, pages 298-321, a full description of local enterprise in canals. The Forth and Clyde Canal, and the Monkland Canal, had not long been completed, as also had the portion from Glasgow, through Paisley, to Johnstone, of the projected Glasgow-Ardrossan Canal. Clelland gives details of the passenger and other services then inaugurated thereon, with a distinctly optimistic view of the future of these. The experience of the last mentioned, namely, the projected Glasgow-Adrossan Canal, gives a vivid local illustration of the unexpected sequel. Not only was this canal never constructed beyond Johnstone, but the only use now made of the portion actually constructed between Glasgow, Paisley, and Johnstone is, that all suitable lengths of it carry one of the railways, known as the "Canal Line," of Mr. Killin's company.

Briefly, the salient historical facts are that, generally, the railways ousted the canals; and thereafter ousted the roads, by taking from them the through traffic which had justified the toll-bar system, abolished about 1880. Later, locally, and in the nineties, our tramways frustrated and arrested the railway companies great efforts in city local passenger transport. Now, generally as well as locally, the petrol engine, in the motor bus, is largely ousting the tramways. For the future, but speaking generally only, Air-Vice-Marshal Sir Sefton Brancker's enthusiastic speech at

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Mr. W. C. Easton, B.Sc.

the "James Watt" Dinner last week should be a warning that aviation may oust the "Royal Scot" of Mr. Killin's company, and other similar long-distance efforts of railways.

My paper, however, deals specifically with city local passenger transport. Into that sphere Sir Sefton Brancker cannot enter. I had personal experience 11 years ago in the construction, by the army, of the initial small aerodrome at Renfrew, immediately prior to the Royal Flying Corps taking it over. A year later I had six months' distinctly intensive experience of the construction of more than half-a-dozen aerodromes in Lorraine, in the area immediately behind the line Nancy to Luneville. From that experience, I have no hesitation in saying that aerodromes cannot be constructed nearer a city than its fringes, as at Renfrew. Consequently, the progress in commercial aviation, forecast by Sir Sefton Brancker, will, if anything, only intensify the demands on city local passenger transport.

Confining myself strictly to city local passenger transport, I now venture to make three assertions. These perhaps should be prefaced by the remark that my apprenticeship was served with a leading railway engineer of his day, Mr. John Strain. These are:—

a. Railway companies, thanks largely to their engineers, do appreciate the two hard matter-of-fact difficulties presented by insufficient width of lines and by crossings on the level. Their engineers do appear seriously to be thinking over these two difficulties, but in the meantime they cannot do more than think.

b. Commercial road transport concerns, on the other hand, do not appear to face these two hard facts. Why, on the short view, should they? With the exceptions, applicable to tramways only, mentioned in § 8 of my paper, the streets are provided for them. Their energies appear to be absorbed in getting the better, often quite temporarily, and in miscalling the merits, of each other. The hard facts in these two

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difficulties, particularly streets crossing each other on the level, will thwart their efforts, and that at no distant date.

c. Private individuals, of all classes, now owning motor cars, with the "Baby Austin" type predominating, will, if things go on as they are doing, shortly waken up to find their movements in city areas severely restricted, if not largely prohibited.

The queries by Mr. Somers, Mr. Dalrymple, Mr. Killin, and others as to who should pay, all lead up to one question, that of policy, which is not an engineer's question. It, nevertheless, points to the need for an inquiry being undertaken by a body sufficiently comprehensive in character, but not too large in numbers, to appreciate all sides of the question. A pertinent, but rather delicate, query would be: Is Glasgow going to continue as a prosperous city?

While the public services should be adequately represented on such a body, representatives of the driving power of private enterprise should not be omitted. The appointing of such a body, with the necessary authority, would take time—a year, perhaps more The hearing and weighing of the considered views of all sections would take further time—another year, or probably more. The working out of the proposal favoured would then take still another year or two. All that, as well as probably considerable negotiations thereafter, would be required before construction work could be undertaken.

This is no time for large capital expenditure. It is, however, the opportunity for thinking out the problem as a whole, so that, when the psychological moment does arrive, progress will be made only on lines of which the cost and consequences have been thoroughly considered. It is quite probable that this progress would then be from stage to stage, on the principle, although not necessarily the lines, indicated in the communication by Mr. Meek, the City Engineer of Manchester. One thing is certain: any solution will involve very considerable capital expenditure.

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Mr. W. C. Easton, B.Sc.

With reference to Mr. Cowan's remarks, destructive criticism is easy. What is wanted is constructive criticism, and for that, time is the essential. Mr. Cowan speaks about decentralisation. As an ideal, doubtless this is good. As a practical proposition, it is directly contrary to all development to-day. For example, whether we like it or not, Glasgow is in many respects becoming a suburb of London. We cannot put back the clock. The facts must be faced. As an example, I would refer once again to the great difficulty which the road men in this country refuse to face, namely, that of crossings on the level of city streets. In the "Engineering News Record," an American journal, of 1st December, this point is emphasised. On the other hand, in a paper read before the Royal Society of Arts on 9th November, the ostrich-like attitude is maintained. The paper emphasises that all that is required is to speed up the traffic in the streets. It completely ignores crossing streets.

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THE USES OF NICKEL DEPOSITS FOR ENGINEERING PURPOSES.

By C. H. Faris,
Member of the Institution.

22nd November, 1927.

The object of this paper is to illustrate the extent to which nickel deposits are being used by engineers, to describe the conditions under which certain tests have been carried out, and to record the results thereby obtained. It is not proposed to review the history of those processes usually termed electroplating, there being so little of interest in them to the average engineer.

It may be stated, however, that, although for many years it has been possible, by the old processes, to impose upon the surface of one metal a very thin layer of a different metal, heavy and perfectly adhesive deposits were not possible, until the appearance of the system under which the following results have been obtained. The older methods, in use 50 years ago and still worked, have undoubtedly served a most useful purpose, but being applicable only to work of a decorative or ornamental character, their field of usefulness did not extend to the needs of the engineer. The main reason which precluded the acceptance of such work into the recognised routine of the engineering shop was the tendency of the film of nickel to flake or peel, due to the absence of adhesion between the two metals, and this serious defect ruled it out of court entirely for engineers, either as a repair measure or as a standard production operation.

In the following pages attention will be directed mainly to the uses of nickel deposited in such a manner and with such

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results that the very exacting requirements are fully met. The experience of the last few years, during which this method has been in use, definitely confirms the view that, in the various branches of the engineering industry, a very real need has long existed for such a process; a cold "putting on tool," as it may be termed, which can be relied upon to produce a sound mechanical job adaptable to the varying and special needs of that industry.

In order to distinguish more clearly between the above-mentioned earlier methods, known as plating, and the process responsible for the work to be later described, the latter will be referred to as "deposition."

Without further reference to what is understood by plating, I may pass to a consideration of the subject of nickel deposition from the standpoint of the mechanical engineer, and with the object of making the paper as interesting as possible I have endeavoured to confine the matter to the practical applications of the system, rather than to lengthy and tedious details of the process itself.

Before entering closely into the details of the paper, it may be helpful to mention that the process in question is an electrolytic one, worked cold on the "still" principle; that each piece of work to be treated is handled separately, put through the various cleaning operations, and finally the deposition operation, all of which are electrolytically applied.

Whether the parts to be thus treated require a heavy deposit which will subsequently be called upon to withstand wear, or only a light protective coating to provide a surface immune from corrosion, it is equally imperative that certain fundamental requirements be specified, if the work is intended to become an integral portion of any mechanism.

In order of importance, these requirements may be placed as follows:—

1. Perfect adhesion.
2. Resistance to wear.
3. Immunity from corrosion.

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4. Absence of heat treatment.
5. Possibility of local application of treatment.
6. Wide range of metals possible of treatment.

Perfect Adhesion.

Because of its extreme importance, the question of adhesion is considered first, and it will be readily conceded that, to be of any real practical use to the engineer, the deposited metal must be perfectly amalgamated to the metal upon which the nickel is imposed.

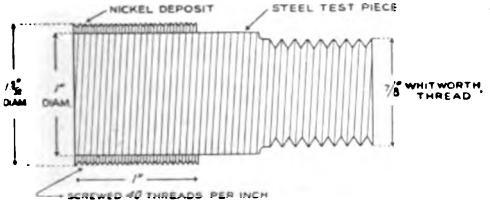

Fig. 1.

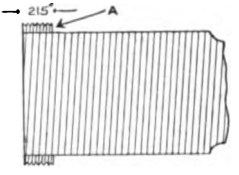

Fig. 2.

Extensive research and experimental work was necessary before it became possible and practicable to obtain the perfectly adherent deposit, unstrippable when subjected to severe tests, in the case of nickel upon steel, but further development and modification have enabled equally successful results to be obtained with other metals.

Throughout all operations absolute cleanliness is essential, and this care, exercised when the electrolytic cleaning is in operation, ensures surfaces free from oxidation or foreign matter which would foul the deposit.

To prove definitely this all-important question of adhesion, a steel specimen was prepared, of the form shown in Fig. 1, and submitted to the National Physical Laboratory, with a request to remove the deposit from the steel and record the pull required to do so. The plain portion of the steel plug, one inch in diameter, was built up by deposition of nickel; then a fine pitch screw having 40 threads to the inch was cut

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upon the nickel, the final diameter over the tops of the threads being $1\frac{5}{32}$ inch. The length of the portion carrying the nickel was, at the commencement of the test, one inch, the maximum thickness of deposit at the thread tops ·078 inch, while the minimum thickness at the root of the thread was ·062 inch. A $\frac{7}{8}$-inch Whitworth standard thread was cut on the other end of the steel plug, on which was fitted a steel holder, another steel holder being fitted to the already-mentioned fine thread on the nickel. The specimen was then subjected to a pull in the same manner as a tensile test piece would be pulled. At a load of 10 tons per square inch, no breaking down of the adhesion was observable.

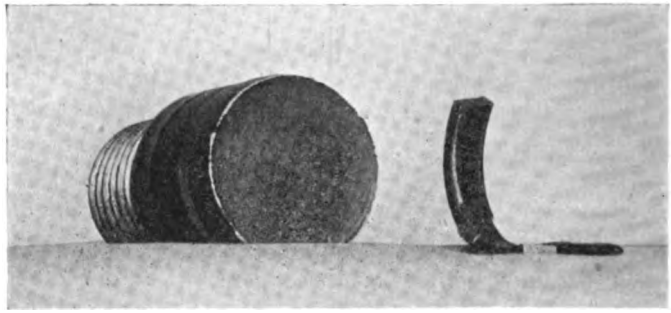

Fig. 3.

With the object of reducing the pull required, the superficial area was reduced by turning away the nickel until the former length of one inch became only a narrow collar ·215 inch in width, as shown in Fig. 2. Again the load was put upon the test piece in the manner described, and at a load of 6·74 tons the thread of the steel holder, which was attached to the 40-thread screw on the nickel, sheared and left the test piece, the nickel thread remaining intact. The steel holder which failed showed, under a scleroscope test, a hardness number of 28.

Thus far the desired information had not been obtained, so to carry the test to finality a special steel holder was employed, which, instead of fitting on to the fine thread, placed

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the load directly upon the end face of the nickel deposit A in Fig. 2. At a load of 11·95 tons, the ring of nickel was pushed from the steel plug, and subsequent calculation showed that the pressure required to move the deposit was 17·6 tons per square inch. The nickel came away from the steel in the form of a ring, broken at one point only in its circumference, and on the inner surface a film of steel was found to be amalgamated with the nickel, proving that even at the load stated, the adhesion was greater than the skin of the steel could withstand, thus the steel sheared.

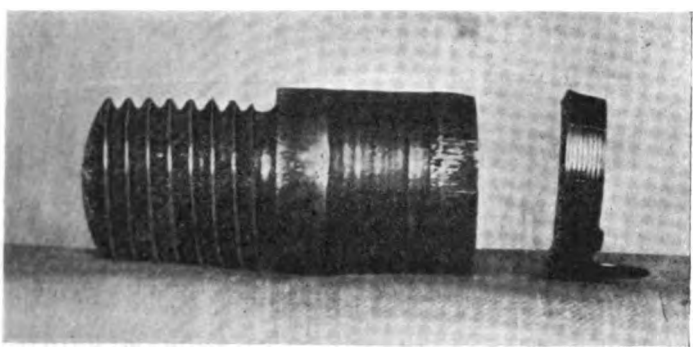

Fig. 4.

It will be noted that the application of the load in the manner described left the thread perfectly free from any compressive force, tending to restrict its movement at such a time as the adhesion should give way, and it may be assumed, therefore, that the adhesion between the two metals was not in any degree assisted by the presence of a steel holder tightly encircling the thread on the outer diameter of the nickel deposit.

Fig. 3 shows the specimen after completion of the test, and particular attention is directed to the evidence of shear on the steel plug, the concave formation on the end face, which prior to the test was perfectly true and flat, and to the presence of the film of steel on the inner surface of the ring of nickel.

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In Fig. 4 the sheared effect is seen more clearly, and the fine thread which was cut on the nickel is seen to be undamaged.

A bar of one-inch bright drawn steel was increased in diameter by nickel deposition to $1\frac{1}{4}$ inch, skimmed up true on the diameter, and short lengths parted off, $\frac{1}{4}$ inch in thickness. One such specimen was subjected to a punch and die test in the

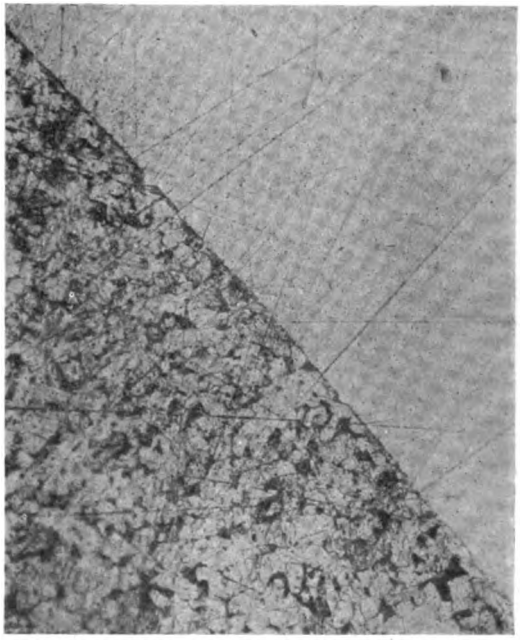

Fig. 5.

laboratory of one of the large steel works in the North, and in that instance a load of 18 tons per square inch was required to push the steel core from the nickel ring, and again the same result was observable, namely, the steel sheared and a film of steel adhered to the nickel.

A further case may be cited of a similar specimen which was dealt with in precisely the same manner. The load in this case, however, on calculation, proved to be just over 24 tons per

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square inch, and again the shearing effect on the skin of the steel was observed.

The microphotograph shown in Fig. 5, of 25 magnifications, is of nickel upon steel; the fine, close grain of the former metal may be noted, also the complete absence of lamination, and particular attention is drawn to the clean line of demarcation

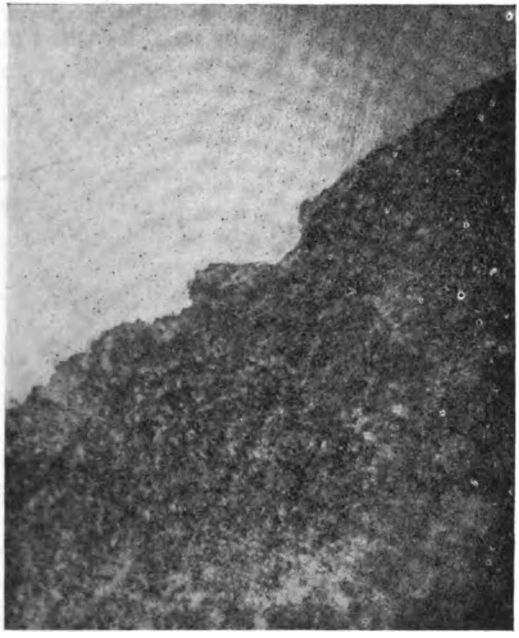

Fig. 6.

existent between the two metals, confirming that no interposed layer of some other metal, such as copper, is present. Fig. 6, which is of 85 magnifications, clearly shows the anchorage produced by the electrolytic cleaning operation, and that the crystals of the two metals are enabled to interlock and become perfectly amalgamated.

The shaft depicted in Fig. 7, a gear-box shaft taken from a four-ton petrol-engined vehicle engaged on goods transport,

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provides an interesting example of the adhesion obtained, and in this instance the test took the form of severe service conditions as an alternative to a laboratory test. On the shaft being dismantled, it was found that the splines at one end had been sheared away, so after a preliminary rough grinding operation on the portion involved, the diameter was increased $\frac{3}{8}$ inch by means of electro-deposition. Subsequent machining produced the finished piece as shown in Fig. 8, where it will be seen that the splines consist of solid deposited nickel, their

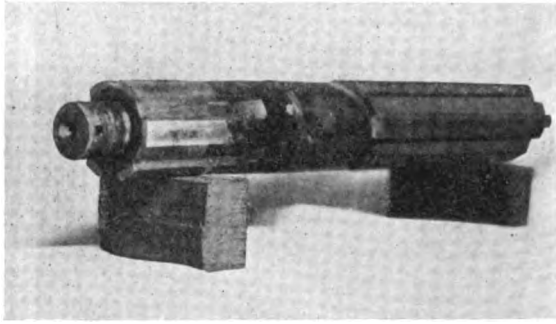

Fig. 7.

dimensions being $\frac{1}{4}$ inch wide and $\frac{5}{32}$ inch deep, the diameter of the shaft over the splines being $1\frac{3}{8}$ inch.

During the spline-milling operation, the cut was intentionally taken deeper than the standard, in order to remove all nickel from the roots of the grooves or keyways, thus breaking up the band of nickel into six separate portions, each approximately equal in width to one-twelfth of the circumference. By this procedure the test for adhesion was accentuated, as each individual spline was subjected to the strain, without deriving any additional strength from the presence of a complete band of nickel encircling the shaft at that part.

It has been shown that the treated portion of the shaft was ground true prior to the treatment, but it should be mentioned that such is not usually necessary, the reason in the case under consideration being to make the ultimate test

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as severe as possible by removing all traces of the former splines, proving that no anchorage is necessary other than that which the process itself provides. Therefore, no mechanical preparation of the surface of the metal to be subjected to this treatment, such as roughening, drilling holes, or cutting grooves, is required, as, providing that the metal is free from scale, and sound, the cleaning bath creates the desired surface and ensures adhesion.

Reports have from time to time been received with regard to the shaft just described, from which it appears that very

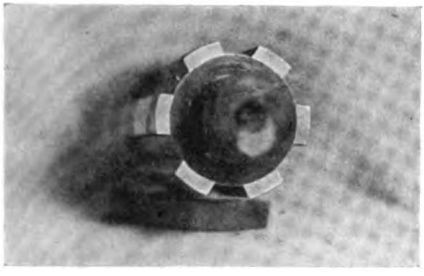

Fig. 8.

little wear, no deformation, and no evidence of loosening of the deposit have occurred during the several years of subsequent service.

On many worn parts ovality is met with, as in the case of motor-engine crankshafts and stub axles, and the machining operation following the deposition process usually produces on such parts, unless a heavy deposit is required, the effect illustrated in Fig. 9, where alternate patches of nickel and steel, coincident with the worn and unworn portions of the bearing respectively, are seen to exist. This condition produces feather edges of infinitesimal thickness at the points where the nickel and the steel blend into each other, but even under such circumstances the nickel will not lift or strip.

As illustrative of this particular point, mention may be made of a repair job carried out on a set of cast-iron pistons and

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gudgeon pins of a Reavell air compressor, which required building up as compensation for wear. After being ground to the correct finished size, feather edges of nickel as just described were produced, but, although the machine has been in fairly constant use during the six years since the repair was effected, a recent report stated that everything was very satisfactory, no appreciable wear, nor any sign of flaking of the nickel at those edges, having been found.

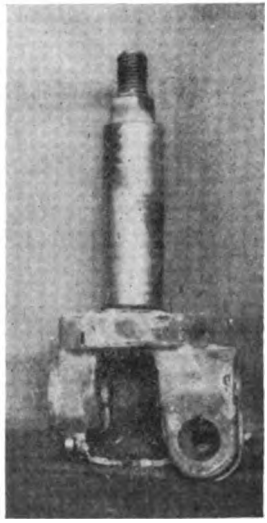

Fig. 9.

An interesting example of perfect amalgamation existing between the deposit of nickel and steel was brought to notice in connection with a crankshaft from the petrol engine of a commercial road vehicle. The crankshaft had been built up on all journals, to restore such worn journals to standard dimensions, and, after having completed 30,000 miles of running, the rear main journal broke, due, apparently, to a flaw. The fracture took place through the centre of the journal, and on examination of the section the depth of the nickel deposit was plainly observable, but the important point

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was that there was not the slightest indication at any point of the adhesion having been affected, the two metals having fractured just as a solid shaft would have done. The actual bearing surface, although 30,000 miles had been covered, was in excellent condition, and, except for the fracture occurring, would have rendered considerably longer service, no appreciable wear having taken place.

Resistance to Wear.

Having established the fact that perfect amalgamation, or adhesion, is effected between the nickel deposits and steel, it is proposed to consider the second requirement specified. A few particulars may here be inserted concerning the nature of the metal, as they bear upon the question of wear resistance to a certain extent. Anodes of a guaranteed purity of 99·9 per cent. are used, the best obtainable being necessary so that the resultant deposits may be relied upon to maintain the high standard necessary when dealing with parts subject to considerable wear. The specific gravity of the nickel is 8·8, one cubic inch weighs ·31 lb. as against ·32 for copper, while the melting point is given as 1,452 degrees C., or 2,646 degrees F.

The Brinell hardness numbers, certified by the National Physical Laboratory on three specimens submitted, were 349, 366, and 377, the variation probably resulting from slightly different treatment. The tests were taken with a 5-mm. ball and a load of 750 kilogrammes. Subsequent tests taken at intervals indicated an average hardness of 360. With the scleroscope, the figure of 55 is often reached, and 60 has been recorded by the National Physical Laboratory, but the average in this case would be 50. An average of 30, results from tests taken with the Herbert pendulum machine, though readings of 32 and 35 have been obtained under that form of test. In work of this nature, however, tests imposed upon pieces of mechanism during actual service conditions commend themselves very strongly as of practical value, and it is considered that a few such instances taken from the mass of information

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available will be of interest. In selecting the following cases for mention, an endeavour has been made to include examples which cover in a general way mechanical engineering, and which emphasise the fact that nickel undoubtedly is an excellent metal for giving longer wear than many unhardened parts.

A vertical steam engine, heavily overloaded and running for 24 hours per day during six days each week, gave continual trouble due to abnormal wear taking place on the gudgeon pin, and replacements were necessary every two or three weeks. One of the worn pins, built up and ground, was again put to work, and at the end of two months was reported as being slightly worn but still in service.

Motor-vehicle stub axles, Fig. 9, when worn, lend themselves particularly to this form of treatment, it being applied without the necessity of heating up the part. A somewhat interesting test, and one of considerable technical importance, was carried through by a firm who operate a large fleet of passenger-carrying vehicles. One pair of nickel-chrome-steel stub axles was drawn from stock, reduced on the stub-arm diameter, which carries the road wheel, to the extent of $\frac{1}{16}$ inch, then built up by nickel deposition and reground to the original standard size, leaving a coating of nickel of uniform depth, approximately $\frac{1}{32}$ inch all round. This pair was fitted to one bus, whilst a second pair drawn from stock, but on which no special treatment had been carried out, was fitted to a second vehicle. The two vehicles were kept in operation under identical conditions so far as routes, mileage, etc., were concerned, and on the completion of 4,000 miles were called in, the stub axles removed, and the amount of wear measured. Micrometer measurements showed that the nickel-covered stub axles had been reduced ·003 inch in diameter, and the steel ones ·008 inch. They were replaced in their respective positions, and the test carried further, measurements being taken at the close of each successive 4,000 miles of running, and at each such inspection it was found that the steel axles had been reduced by twice the amount of the nickel-covered ones.

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Another instance, similar to the one above mentioned, relates to a stub axle on motor-bus work in the Carlisle district which was reported to have completed 30,000 miles of running when last examined, and no wear had taken place.

In view of the fact that nickel has not been used to any great extent as a bearing metal, these figures may appear surprising, but the fine close grain of the metal, the refining effect produced by the electro-deposition process, and the lower coefficient of friction which it is known to possess, all contribute to its suitability as a bearing metal.

It is not claimed that the metal, which is not subjected to any hardening process subsequent to deposition, will stand up to work usually performed by casehardened steel, but it is of interest to note that casehardened steel camshaft contours have been thus built up when worn, and after remachining to correct form, have given a length of service equal to that of the original cam. It should be stated that this has occurred in every instance where a roller is interposed between the cam and the tappet.

Swivel pins on commercial vehicle front-axle work also are found to resist wear better when nickelled, as the immunity from corrosion has a retarding effect upon the abrasive action, preserving a smooth and bright surface, as against the usual roughened surface. Such a swivel pin has completed 25,000 miles without appreciable wear, and with better results than when casehardened and fitted new.

The last reference to wear in connection with automobile work is that of a crankshaft from a Sunbeam car which, after all the journals, nine in number, had been reinforced and brought up to original standard, completed 70,000 miles of running during the last five years. During that period the engine was only once overhauled, and the crankshaft reground to eliminate slight ovality which was present, but the regrinding operation did not remove all the deposited nickel, and thus the journals are still nickel covered.

Turning to locomotive practice, mention may be made of gudgeon pins, reversing screws, and jack links, which, after

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being salved from scrap badly worn, were tested out on main-line work. Records were kept of the parts referred to, and showed that a considerably longer life was obtained from these parts than from ordinary steel ones. A gudgeon pin, made intentionally small to allow for the nickel and then machined back to standard after deposition, is still under trial with a view to balancing the extra small cost of production against the additional life obtained.

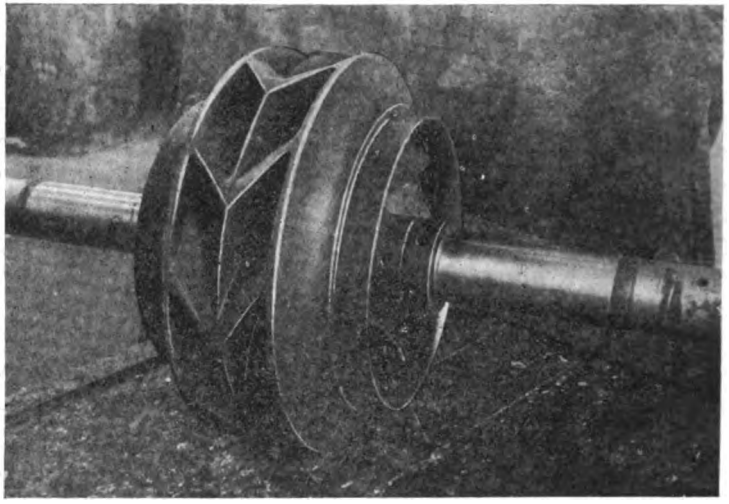

Fig. 10.

For marine work as well as for land installations, phosphor-bronze impeller shafts for centrifugal pumps, reinforced in this way when wear and erosion had rendered them unfit for further duty, are reported to be giving good results in service, their life being approximately three times greater than formerly, thus amply justifying the expense of reclamation. An impeller shaft of this type, very heavily worn on the two gland journals, is shown in Fig. 10. All the work was carried out without removal of the impeller from the shaft, which was 3 inches in diameter, the diameter of the impeller being 22 inches, while the total weight was approximately 3 cwts.

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Fig. 11 depicts another bronze impeller shaft, also for centrifugal-pump work, for marine service. The gland bearings are finished to $2\frac{3}{4}$ inches diameter, and the overall length is 36 inches.

A de Laval turbine spindle at work in a northern municipal electricity generating station, and running at 6,500 r.p.m., has

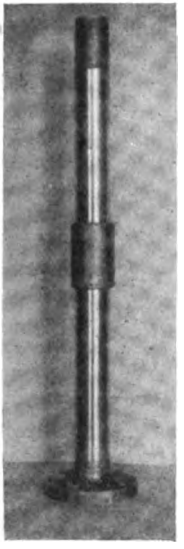

Fig. 11.

the journals built up in this way, and works quite satisfactorily. It is known that hydraulic plungers and rams thus treated are capable of far longer duty, because the absence of corrosion assists in withstanding wear, an instance of this being afforded by a hydraulic plunger at work under 4,000 lbs. pressure, which, after 12 months' continuous work, shows neither wear nor corrosion.

Immunity from Corrosion.

Corrosion affects so many industries and branches of the engineering trade that the question is receiving considerable

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attention, and every endeavour is being made to arrest the yearly wastage of material attributed to this cause alone, the value of which Sir Robert Hadfield placed at approximately £500,000,000. It is evident also that, in addition to this great loss, there must be a still further loss in the non-operative time of the plant, during which replacements of corroded parts are carried out, as in the case of hydraulic plungers, steam-turbine blading and nozzle-plate diaphragms, and valve work.

Whilst research work has steadily proceeded along the lines of finding metals capable of resisting various corrosive actions, *e.g.*, monel metal, other non-ferrous alloys, and the alloys known as stainless steel, the complete solution is yet far from being reached. Alloys, it would seem, are more readily attacked than pure metals, hence the difficulty of providing a pure metal resistant to corrosion on the surfaces involved, yet possessing the physical properties required to enable erosion or wear to be withstood.

A further field of research is concerned with the application of various non-metallic coatings, but on metal-to-metal parts that, of course, is useless. Various methods of applying protective metallic coatings are also being tried, but their use appears to be considerably restricted because only extremely thin coatings are imposed, and the degree of adhesion with such coatings falls short of the requirements of the mechanical engineer.

In addition to the direct corrosive action so far dealt with, there is a further and equally serious one to be considered, namely, the acceleration of wear primarily caused by corrosion. Parts exposed to the action of steam or water, when out of action, become oxidised, as in the case of a regulator valve rod on a steam engine or the spindle of a steam valve. Immediately the part is put to work again, the fine film of oxide is removed. It probably acts as an abrasive powder during subsequent movement, and with repeated movement its diameter is appreciably diminished. Too much stress cannot be laid upon this very important aspect of the situation,

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for on working parts wear or abrasion takes place much more rapidly if the bearing surfaces become affected in any way by a corrosive agent.

As is well known, nickel is an excellent metal for resisting corrosion, due perhaps to the action of the atmosphere,

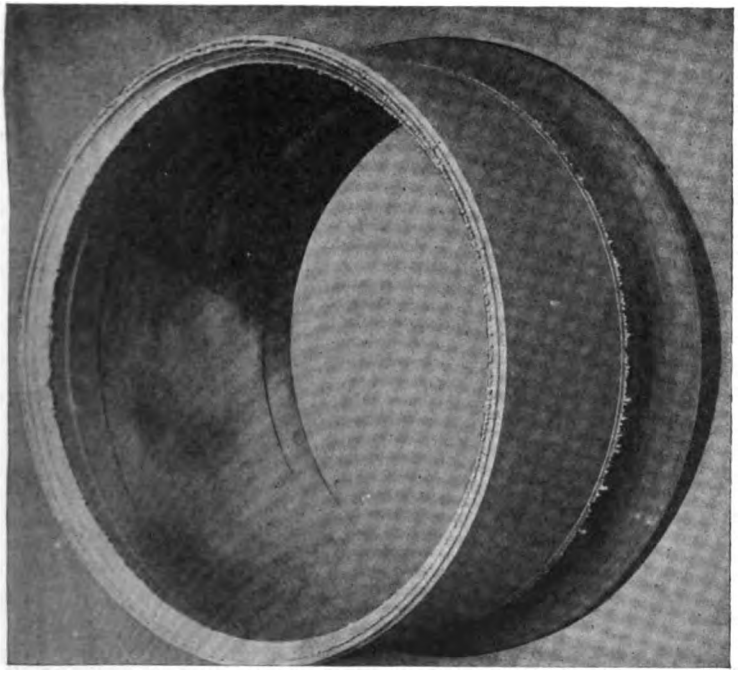

Fig. 12.

moisture, sea-water, or certain fats, chemicals, and oils, but except for exceedingly small parts, and only in such cases as justified the expense, mechanical parts have not to any large extent been constructed of solid nickel. It is advocated, therefore, that many parts now constructed of non-ferrous metals be made of steel, and protection against corrosion be ensured by the provision of an outer layer of pure nickel, electro-chemically deposited. A metallic coating thus applied

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should be resistant to the particular form of corrosion involved, should be homogeneous and perfectly united to the underlying metal, and must be capable of application without recourse to any form of heat treatment.

A steel rod, with a coating of nickel equal in depth to ·005 inch, was suspended at half-tide in the sea, off Dundee,

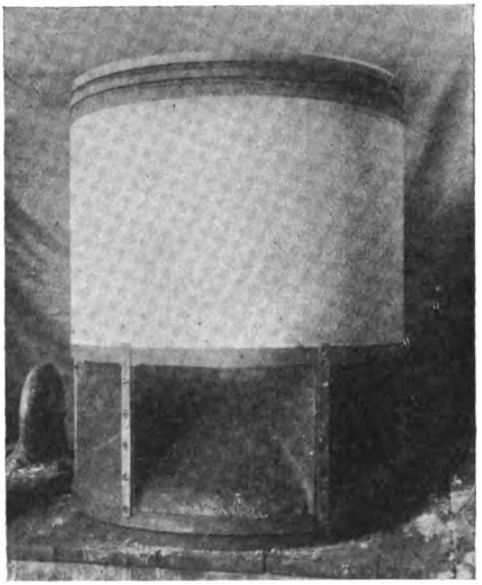

Fig. 13.

for a period of nine months. An inspection of the specimen on removal showed that the nickel surface was unaffected, although the alternating immersed and dry periods constituted a fairly severe test. After being similarly tested for a further 12 months, the same condition was noted; the sea-water had not acted upon the nickel or caused any tendency to strip.

In Fig. 12 is shown a cast-iron piston for hydraulic work, 38¾ inches in diameter and weighing approximately one ton, while in the example shown in Fig. 13 the outer diameter

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is 32 inches and the weight about 15 cwts.; on both of these parts a light protective coating of nickel has been deposited.

The following data, based on actual service reports, will, it is thought, lend support to the suggestion that where such nickel deposits have been called into use, economy and efficiency have been obtained.

On a caustic soda plant, much trouble was experienced with corrosion and wear of the plunger, and after several metals had been tried, a monel plunger was adopted, but it only lasted three months. A steel plunger, having a protective coating of deposited nickel, $\frac{1}{32}$ inch thick, was substituted, and at the end of eight months' continuous service, working 130 hours per week at a pressure of 400 lbs. per square inch, it was stated to be quite satisfactory and only slightly worn. When the plant is started up, grease is applied to the plunger, but the caustic soda soon appears to dispel the grease, and itself becomes the lubricant, thus severely accentuating the untoward conditions. When wear eventually renders the plunger unfit for service, an auxiliary plunger which has been prepared in the same manner will be fitted, and the worn one renickelled; the steel portion will thus be practically everlasting.

In an oxygen compressor another steel plunger, similarly coated, is operating with unqualified success, and after nine months' arduous duty is stated to be in better condition than when first fitted, there being no appearance of wear or corrosion. This replaced a phosphor-bronze plunger, the normal life of which was considerably shorter than nine months, and close observation of the part in use leads to the conclusion that the film of water, which in this case is the lubricant, by clinging well to the highly-polished nickel surface, enables it to retain its high polish, and when shut down no oxidation takes place. The improved conditions, aided by the lower coefficient of friction, not only prolong the useful life of the plunger, but it has been found that the leather packings are lasting four times as long as formerly. A further appreciable

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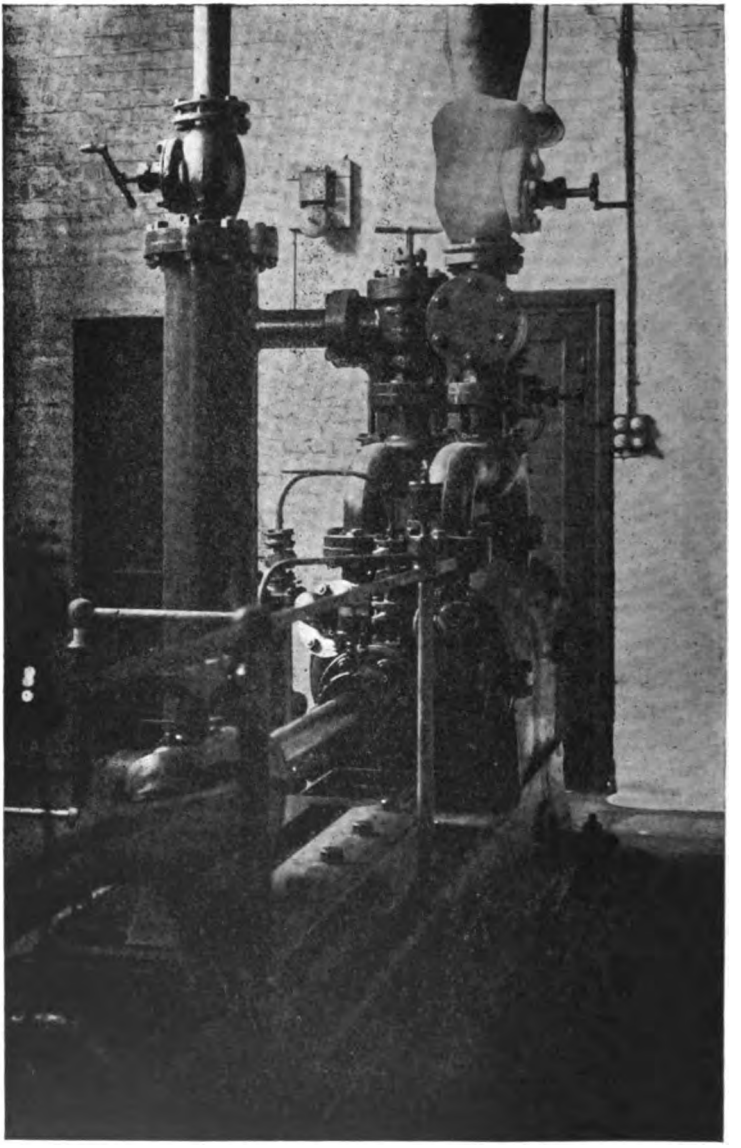

Fig. 14.

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saving is thus effected, not so much in the value of the leathers as in the saving of shut-down periods, which were necessary for the operation of repacking.

Fig. 14 shows an ammonia compressor which is working in one of the largest refrigerating plants in the country. It is fitted with a rod which has been reinforced on the diameter,

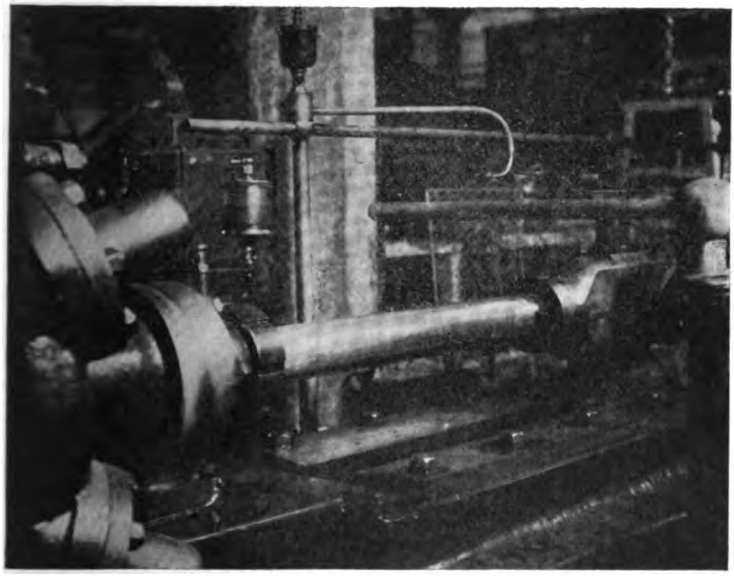

Fig. 15.

as compensation for wear and corrosion, and is reported to be quite successful, the nickel surface being unaffected by the ammonia.

In Fig. 15 is shown a close-up view of the rod, which is $3\frac{3}{8}$ inches in diameter and 6 feet in length. The central treated portion is 4 feet 9 inches long, but only a part of it is seen, as with the rod fully extended at the end of the outward stroke a considerable length still remains in the gland.

Although the procedure mentioned is being increasingly adopted as a repair measure, the economy effected is so

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considerable that its application to new parts would seem desirable from the point of view of those engaged in operating plants for chemical, steam, and refrigeration purposes. It will be agreed that to manufacture parts capable of resisting destructive agencies, even if by so doing the normal life is only trebled, is preferable to dealing with the effects of such corrosive actions after the plant is put into operation. The question of comparative costs here arises, and as an illustration the case of the steel plunger working in caustic soda may be taken.

The cost of the steel, the preliminary machining followed by deposition, and finally, the grinding to finished size, would not exceed the cost of the plunger when made from monel metal or stainless steel, yet assurance is forthcoming that the life thus far obtained has exceeded the maximum life ever obtainable from monel metal in the proportion of three to one. In other words, during the period in which the nickel-coated plunger has been in use, three monel metal ones would have been worn out and scrapped, each of which would have cost the same as, or possibly more than, the one in question, and when worn are scrap metal, whilst the worn steel plunger may be again coated, which is a further economy. On a nitrous oxide plant, the experience with a plunger having a coating of nickel, electro-deposited, is in line with the examples already quoted.

Further applications may be cited, namely, motor-engine cylinders exposed to the action of salt spray on launch work, piston dipper tubes for Diesel-engine work, and particularly vessels and appliances used in the foodstuffs and confectionery industries, where it is well known that, for most foods, nickel is the best metal to employ if prevention of contamination is desired. Few organic acids have any appreciable effect upon nickel, but it is affected somewhat by nitric acid, and to a greater extent by aquaregia, whilst it is not affected at all by alkaline solutions, thus rendering it of use on ammonia plants.

To engineers, the use of nickel deposits in connection with

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steam plant is a matter of direct concern, particularly in the case of parts exposed to the action of superheated steam.

Fig. 16 illustrates a valve spindle for a large generating station in the Midlands. The scored and corroded spindle, $2\frac{1}{8}$ inches in diameter, was restored to the original dimensions by the deposition of nickel, the cost of the restoration being considerably less than that of a new spindle.

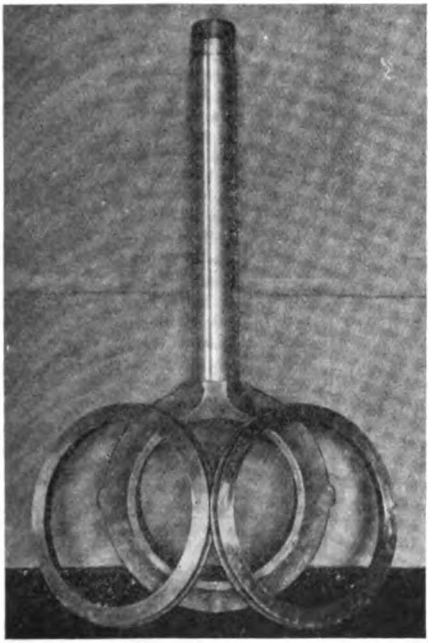

Fig. 16.

Expansion sleeves as used on marine work provide a further instance of the useful employment of nickel in this form. The expansion sleeve shown in Fig. 17 was the first one treated for the S.S. "Mongolia," and was dealt with as follows:— Wax stopping having been applied to the centre portion, near the ports and the flanged end, as well as the bore, a coating of nickel, sufficient to replace the metal lost by pitting and

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corrosion, plus machining allowance, was deposited. The sleeve was then skimmed up in the lathe, and after polishing with emery cloth was again fitted in the steam line. It should

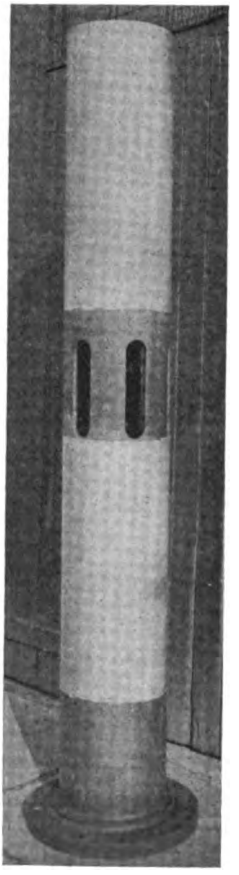

Fig. 17.

be explained that, owing to the pitting action taking place on the external diameter of the steel sleeve, it was impossible to obtain proper seating of the metallic packings which were fitted on each side of the centrally-cut ports.

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Prior to the treatment, the sleeve described had to be removed after each voyage, skimmed up smooth, and again fitted, until the diameter was reduced to a point below which it was not considered advisable to proceed. After several passages between Australia and the home ports, the sleeve was withdrawn for inspection, found to be in a satisfactory condition, and put back. The remaining sleeves on that vessel were treated in the same way, and on the completion of 18 double trips were reported to be in good condition and quite satisfactory. The success of this class of work seems to be the result of the highly-polished nickel surface retaining its polish and smoothness, thus facilitating perfect seating of the packing and effectually preventing steam leakage.

Several of H.M. cruisers and other naval vessels are fitted with this type of steel sleeve, and protected from the superheated steam by a layer of nickel. A number of sleeves have also been treated in a smilar manner for torpedo-boat destroyers built in Holland for the Dutch Government, the sleeves being sent to London for the treatment required. Much of the valve work, such as seats, spindles, etc., on H.M.S. "Ambuscade," one of the vessels fitted with the special sleeves, is also protected in the same way against superheat. A specimen of steel so coated was suspended in a steam separator for six months at a temperature of 700 degrees F. without any detrimental effect being noticeable.

Numbers of steel turbine-blades thus protected have been fitted in various power plants, the depth of nickel varying from ·002 to ·005 inch. The reports received upon these after inspection have been very gratifying, and indicate a wider application to this class of work. Nozzle plates also, for steam-turbine work, lend themselves particularly to such treatment, and it may be of interest to record the steps taken to eliminate corrosion on such parts, in connection with two vessels repaired at Liverpool for Messrs. Furness, Withy & Co. On opening up the turbines, it was found that, while most of the nozzle plates were not so badly corroded as to warrant scrapping, there were some sections which could not possibly be used

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again, corrosion having proceeded very extensively. In the case of the usable ones, nickel was deposited all over each plate, the diaphragm itself being stopped off, and by so doing it was possible to bridge over the joint between the edges of each plate at the points where they enter the metal of the diaphragm, thus affording protection at a usually vulnerable

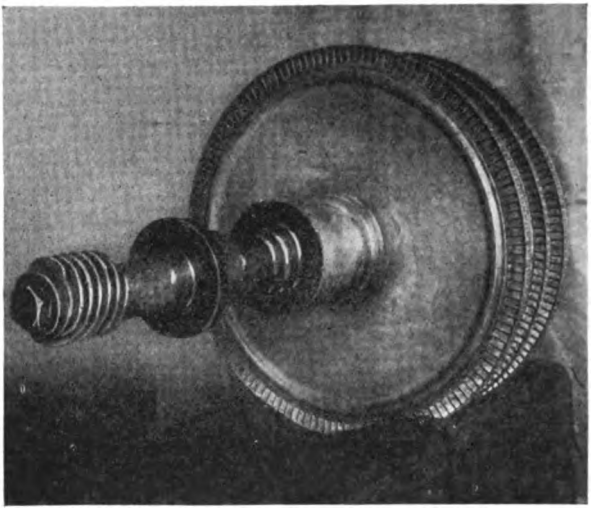

Fig. 18.

point. The new plates were nickelled before moulding into the diaphragm, as such a procedure lessens the cost, but the first-mentioned method is by far the better, even on new work, and is, therefore, recommended.

The turbine rotor depicted in Fig. 18 is of special interest, as the shaft is made of stainless steel. The steel wheels and bronze blading are coated with nickel for protective purposes, the three metals receiving simultaneous treatment. It may here be mentioned that in machining, stainless steels present greater difficulty than those steels not possessing the same high chromium content; thus the machining times are

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increased, which involves greater expense in the upkeep of tools.

Absence of Heat Treatment.

Improved design and advanced methods of construction, resulting in the attainment of increased strength and higher efficiency, have necessitated close study on the part of metallurgists in their endeavour to provide suitable steels and materials for the special requirements of engineers. On special steels, the heat treatment largely decides the success or otherwise of the material, and, if possible, should not be interfered with by intermediate heating up, as in welding. A process such as the one forming the subject of this paper, is particularly applicable in such cases, as heavy deposits for building up undersized portions, or light coatings for protective purposes, may be imposed without the application of heat.

Freedom from distortion is also desirable, especially in the case of cast or malleable iron parts, and while welding is sometimes resorted to as a means of salvage on worn or wasted parts—and there are cases where such is more expedient than electro-deposition—there exist strong reasons for avoiding welding where possible, especially on parts of such importance as automobile steering mechanism. During actual deposition, the work under treatment is not subjected to a higher temperature than that of the solution in which it is immersed, and that is, approximately, 80 degrees F. On parts requiring only certain surfaces to be treated, a specially prepared wax compound of low melting point is used to stop off the surfaces on which nickel is not required, and on completion of the work the wax is removed by immersion in hot water; but in the case of parts of fragile construction, and liable to slight distortion, the hot-water dip is omitted.

Possibility of Local Application of Treatment.

Other than those parts which require light coatings as a measure of protection, practically all the work dealt with calls

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for localised treatment, and this is effected by the use of the wax preparation, which ensures that no electrolytic action occurs

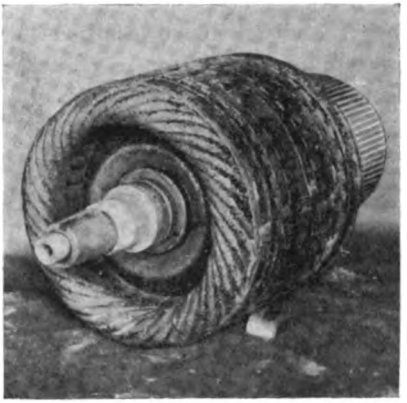

Fig. 19.

on the surfaces which have been so covered. By the adoption of these means, it is possible to build up one side only of a

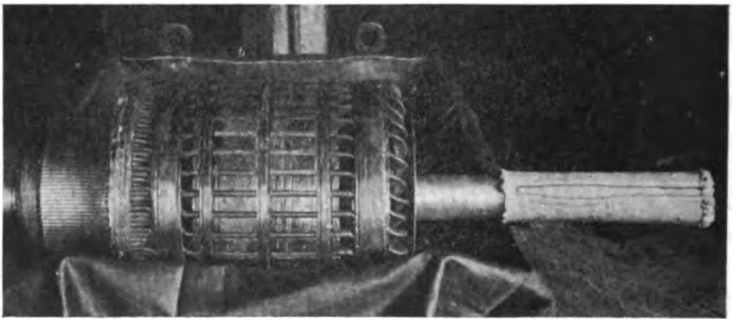

Fig. 20.

worn or deformed keyway or spline without the slightest interference with adjacent finished surfaces, such as tapers or journals. The worn part of a screw thread may thus be built up and recut in line with the unworn portion, and so

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also may a single cam on a camshaft, or even the worn portion on the contour of a cam.

Fig. 19 illustrates an armature shaft, built up on the ball-race seating, which had been rather badly scored through the ball race commencing to creep, and finally failing in service. By protecting the commutator and windings in several thicknesses of canvas material covered with wax, which is quite impervious to the solutions, no harm was caused. In such a case the immersion in hot water for removal of the wax is, of course, omitted. The seating in question is close up to the end plates within the recess formed by the windings, a difficult job to handle by welding without withdrawal of the shaft, which in this case was unnecessary.

Similar precautions were also taken with the armature illustrated in Fig. 20, which in order to complete required the grinding of the shaft and recutting of the keyway. The weight of this armature was nine cwts., but the handling of even larger sizes presents no special difficulty up to a total weight of two tons.

Range of Metals Possible for Treatment.

Thus far the work reviewed has consisted mainly of steel parts, though passing reference has been made to parts made in other metals. The earlier experiments were practically confined to the application of the system to steel of different qualities and conditions, until eventually it was possible to deal with casehardened as well as tempered steel, and recent developments have enabled deposits of nickel to be imposed upon steels of the stainless variety. The advantage will be readily seen in the case of tempered parts, as springs can be rendered resistant to corrosion without any alteration to their temper.

Cast and malleable iron were later dealt with, but with these materials it is essential that the metal be sound and free from blowholes or sandy patches. These remarks apply also to phosphor-bronze, manganese-bronze, and gunmetal, all of

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which may be reinforced when necessary by suitably varying the methods. It is suggested, however, that while nickel deposition upon such materials, in the form of plungers, valve-spindles, pump-shafts, etc., is desirable as a repair or salvage measure, from the point of view of economy and increased life, the ideal arrangement would be the manufacture of such items from a mild steel possessing the physical properties necessary to ensure strength, with a nickel coating of suitable thickness to resist erosion or corrosion.

The subsequent machining of parts made from the alloys just mentioned, and especially in the case of cast-iron, presented certain difficulties. It was found that the tough close-grained nickel did not yield readily to tooling operations, and the cutting edges soon became dulled. The strain then imposed upon the work was frequently more than the underlying metal could stand, with the result that, instead of there being a clean cut, a portion of the deposit would be pushed off with a part of the base metal adhering to it; thus it became evident that, although the adhesion was all that could be desired, the material under treatment, especially with the soft grades of cast-iron, failed to stand up to the strain during machining.

Particularly difficult in this respect were cast-iron pistons for automobile work, on the bands separating the ring grooves, which in some instances were less than $\frac{1}{8}$ inch in width. This difficulty was overcome largely by substituting grinding operations, wherever possible, for all plain surfaces and diameters, including crankshaft journals and cam contours. Splined work, keyways, screw threads, etc., are usually machined, however, and by care and the avoidance of crowding on the cut too much, no special difficulty appears now to exist, but, as in the case of the grinding wheels, the various tools are worn out in an appreciably shorter time. For lathe work where grinding is not resorted to, attention should be given to the proper choice of rake and the cutting angle of the tool to be used.

Satisfactory results are also possible with aluminium, which

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in the past has yielded less readily than other metals to any form of treatment involving the application of heat, and it would seem, therefore, that the results previously aimed at by heat application, such as welding, soldering, etc., are now rendered possible by means of a process requiring no heat. To obtain the best results, however, it is essential to know the analysis of the alloy to be treated. A specimen of nickel upon

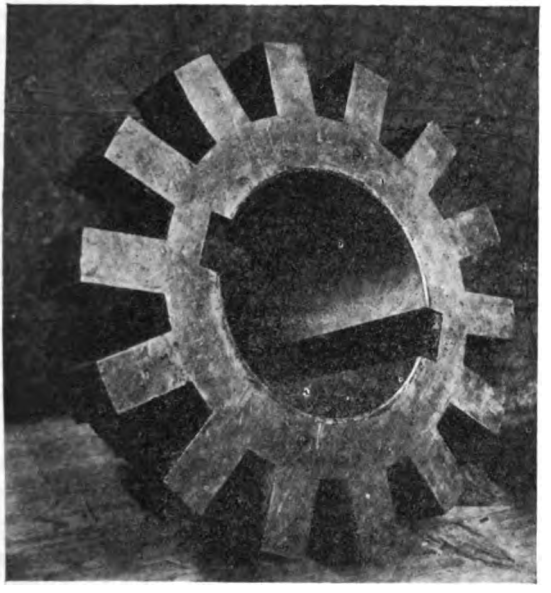

Fig. 21.

aluminium, similar in many respects to the steel test piece described earlier in the paper, was submitted to the National Physical Laboratory. The report issued by that authority showed that the load required to remove the deposit was three tons per square inch, and, as in the case of the steel plug, the deposit took away a film of the underlying metal, the skin of the aluminium being definitely sheared. To meet special requirements, nickel deposits have also been imposed upon monel metal and stainless steel, in some cases to salve a worn

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part by reinforcing and remachining, and in other instances to render the part less liable to corrosion.

In order briefly to describe the method of handling, especially of large work, the flexible coupling shown in Fig. 21 is taken as an example. This coupling is fitted to a 1,500-h.p. turbo-generator at one of the large municipal electricity generating stations in the Midlands. It has a bore of 10½ inches, the outer diameter being 24 inches, and the weight approximately two cwts. Play had developed between the bore and the shaft. The latter was, therefore, trued up *in situ*, whilst the bore was built up and reground to suit the reduced shaft diameter. The first operation was the attachment of a suitably-sized copper wire to act as a conductor during the subsequent electrolytic treatment. Using the already existing holes in the face of the coupling for eye bolts, the job was transported on the overhead runway, and immersed in the tank containing the waxing preparation previously mentioned. The wax was then carefully removed from the bore, leaving the rest of the job, including the keyways, covered. Immersion in the electrolytic cleaning bath next took place, and this operation effectually removed all particles of foreign matter and traces of oxidation which would otherwise interfere with the adhesion of the nickel. After swilling in water, the work was transported to the nickel deposition bath, in which it remained until the bore was reduced sufficiently to compensate for the amount by which the generator shaft was reduced, plus machining allowance.

There is no fixed rule as to the time required to carry out the operations mentioned, the solutions as well as the current being regulated to suit the conditions of each job. As an approximation, however, the coupling under consideration required to be immersed for deposition, without disturbance, for nine days.

For measuring purposes, ordinary gauges and tools are used, and in order that the operator may see his work, a powerful electric lamp, suitably mounted in ebonite, is lowered into the solution, as all measurements are taken whilst the process

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of deposition is proceeding. When up to the required size, the work is removed, cleaned off, stripped of wax and wire, and then machined. By such means it is possible to handle individual parts weighing as much as two tons, while the larger vats employed, which are 8 feet long by 5 feet wide and 6 feet deep, permit of diameters up to 48 inches being dealt with. The vats in use are of pitch pine, very substantially constructed, lead lined, and autogeneously welded at the joints.

At the present time it is not considered advisable to exceed the figure of 22 square feet as the maximum superficial area to be treated at one operation, either for cleaning or for deposition. As that limiting factor, however, is but a stage reached in the development of this work, it is anticipated that much larger areas will be satisfactorily dealt with in the near future.

Electric power is taken from a company supply, and passed through 3,000-ampere motor generators, three of which are installed. These charge the large accumulators, which measure 6 feet by 3 feet by 2 feet, and from which the process takes its current supply.

I have endeavoured in the foregoing pages to show the degree of reliability now obtainable in connection with heavy deposits of nickel, to illustrate the extent to which such deposits are used, and to indicate the further wide field of usefulness open to such work. To appreciate fully the value of such deposits, it is necessary to dismiss from the mind all the earlier experiences of "plating," and instead of viewing the matter as a "doctored" piece of work, to consider it in the light of the tests carried out and the results obtained, as recorded in this paper.

Although it is not possible to explain in detail another development of the methods employed, because the work is still in an experimental stage, it is thought that a brief reference should be made to a matter of great importance to marine engineers and power-plant specialists. Condenser tubes are a problem, from the point of view of failure through

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corrosion or erosion, and the discussion which followed the paper recently read by Sir Charles Parsons before the Institution of Naval Architects, showed this to be the general belief. Evidence was forthcoming that an urgent need exists for some solution to the problem, which will be not only effective but commercially practicable. Research has actively proceeded along the lines of providing suitable materials to resist both erosion and corrosion, and although the tubes manufactured from materials possessing a high nickel content, such as cupro-nickel, appear to give longer service and better results, the cost is high and in many cases prohibitive. If the inner surface of brass condenser tubes can be protected by a coating of pure hard nickel, unstrippable, it is reasonable to suppose that their life will be considerably lengthened. Tubes so treated are now in service and under test.

Although this work has only been carried out experimentally, and not on a large scale, it is hoped that in the near future a plant will be in operation capable of dealing with large numbers of such tubes. Further information will be available shortly when the tests are completed, but it was thought appropriate that at this stage mention should be made of what promises to be a solution of the condenser tube corrosion trouble.

I desire to thank the Trafford Park Cold Storage, Ltd., of Manchester; Messrs. Henry Wallwork & Sons, of Manchester; and other firms, who have so kindly given permission for illustrations to be shown, or who have placed data at my disposal regarding the service of parts subsequent to treatment. To Messrs. Fescol, Ltd., of London, thanks are also due for the loan of samples and for information relating to the various tests mentioned in the paper.

Discussion.

Mr. DONALD MACNICOLL (Member): There is no doubt that the process described by Mr. Faris will be adopted for a variety

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Mr. Donald MacNicoll.

of purposes and to a considerable extent in the future. In some expansion sleeves treated in this way for H.M. cruisers, it appeared to me that there was considerable porosity in the deposit, although I may have been wrong in thinking so. I quite appreciate that for an expansion sleeve this might not be a vital fault, but I am afraid it would be in the case of valve and valve seat faces, where, in many instances, a deposit of about $\frac{1}{4}$ inch deep would be necessary to allow for regrinding or taking out cuts and dents once or twice, and still leave $\frac{1}{16}$ inch of the deposit. The deposit for larger valves might be about $\frac{3}{4}$ inch in breadth, and it would be interesting to know how long it would take to make a nickel deposit $\frac{3}{4}$ inch broad and $\frac{1}{4}$ inch deep on, say, a 15-inch cast-steel valve for a cast-steel seat, whether the deposit would be free from porosity, and also whether any trouble would arise from the difference between the coefficients of expansion of the nickel and the cast steel.

Mr. William Wylie (Associate Member): About ten years ago an engineering firm in Glasgow installed a three-throw pump to draw water from the canal. During its ten years' life, the rams, glands, and neck-rings were replaced three times. At the next overhaul it was found that the gunmetal rams had been greatly reduced in diameter, so, in order to bring the pump up to its full capacity, new mild-steel rams covered with a nickel deposit were supplied. New gunmetal neck-rings and cast-iron glands were also coated on the rubbing surfaces. The deposit was about two-thousandths of an inch, and half-a-thousandth was ground off. It was thought that the water would be a sufficient lubricant to minimise friction, but after about two hours' running it was found unsuccessful to run nickel to nickel in this case. Plain gunmetal neck-rings were, therefore, fitted, and the glands bored out and bushed with gunmetal, which got over all difficulties. Under these conditions, the pump has been working continuously and without any extra supervision for several months, and has given no trouble whatever.

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Mr. William Wylie.

Mr. Faris refers to a steel rod which was immersed in the sea off Dundee. I should like to know what examination was made of the rod, whether any heat was applied to it at any time afterwards, and if so, to what temperature, and what were the results of the microscopic inspection. Figs. 12 and 13 resemble parts of cylindrical balanced valves similar to the type constructed by the firm with which I am connected, and I should also like to know if Mr. Faris can give any results as to their working.

I understand that in one of the large gas works in London the process described in the paper has been used with very satisfactory results for rebuilding crankshafts. In the early days, the greatest trouble was in getting rid of the oil which had saturated the material. That trouble has now been overcome with very satisfactory results, and the life of some distorted parts has been considerably increased.

It would be interesting if Mr. Faris could give any figures for actual work carried out, showing that nickel deposition is an economical method of dealing with certain standard articles, such as the valves and valve seats which have been fitted on certain ships.

Mr. William Brown (Member): This paper indicates the enormous economies which may be practised in engineering by the use of a nickel coating applied by the process so well described by Mr. Faris. It is indeed difficult to say how far these economies may be carried, in view of the splendid adhesion obtained by the process and illustrated so clearly by the photomicrographs. I wish to ask Mr. Faris how the nickel coating behaves when in contact with red hot metal. For instance, in the case of a rolling mill, rolling, say, steel plates for ships, if a roll were covered with nickel, would its life be increased by 50 or 500 per cent.? Would the surface remain smooth for a long time, or would the hot metal injure the nickel deposit very quickly? If the nickel deposit will stand up to the wear and tear of hot metals, then its field of usefulness is almost unlimited.

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Mr. C. R. H. Bonn.

Mr. C. R. H. Bonn (Associate Member): Electro-plating, as a means of protection and of improving the appearance of an article, has long been extensively practised, but hitherto, with the most careful preparation of the bath and regulation of the temperature and the current density, it has been difficult to obtain a fine crystalline, non-porous, perfectly adhesive deposit, even when thin. A thick deposit of this nature was almost, if not quite, impossible, especially with certain metals, and in the case, say, where a worn part had to be made up, it was necessary to deposit alternate layers of nickel and copper in order to obtain the required density and adhesiveness in the deposit, so that it could successfully resist wear and tear.

At the same time, it has long been known that, as regards the nature of the deposit obtained, nickel baths improved with age. It did not seem clear why this was so. It was thought that, after standing for a time, the bath gave up some of the dissolved gases which were known to have a deleterious effect, because if the contents were agitated or filtered the improvement was lost. Again, adding certain colloidal materials to the bath, even in very small quantities, was known to improve it, but I have never been able to find out if this aspect of the matter was thoroughly investigated. I believe it is a fact that hydrogen, which is given off at the cathode, is found entrapped in porous deposits. The entraining of hydrogen would be most liable to occur with high-current densities, that is, simultaneously with porous deposits, and the problem may thus resolve itself into one of the elimination of such hydrogen. I mention these points because they concern the technical side of the process, and are naturally interesting to a technical institution, and Mr. Faris has avoided all reference to them.

It seems like splitting hairs to distinguish this process from similar processes by calling it electro-deposition, because, however great an improvement, and the improvement is self-evident, it is still essentially electro-plating pure and simple. I should like to know if this process is patented, so that those interested may not be tempted to trespass.

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Mr. John S. Brown, M.B.E.

Mr. JOHN S. BROWN, M.B.E. (Member): It may be of service to notice that the historical side of this subject does not pass directly from the nickel-plating used on bicycle handlebars to the substantial coatings described in the paper. In the first place, the original nickel-plate was merely a top layer of nickel deposited on a first coating of copper, and as such its mechanical properties were restricted to those of the copper. Then the war period brought a critical situation where the supply of motor lorry spare-parts could not be maintained at the repair depots in France, and this led to a process being developed for depositing pure iron on the worn surfaces. I understand that considerable difficulties had to be overcome before these iron deposits became satisfactory. And, of course, it still remained necessary to case-harden such work to obtain wearing surfaces, and this involved possibilities of distortion. It is, therefore, very interesting to find that a nickel deposit can now be made without any copper undercoat, and that this nickel should possess almost wonderful properties in standing up to wear in a way which we have come to regard as confined exclusively to case-hardened surfaces. The wide variety of parts on which this process has been successfully applied is not the least interesting part of the paper, and it would seem that engineers have been provided with a tool of very considerable importance.

Many of the examples refer to parts which are called on to work at relatively high temperatures, and these are evidently giving satisfactory service. But there is presumably some limiting temperature, as the linear expansion coefficients of iron and nickel are not identical, and this must eventually impose stresses beyond the elastic limit in the nickel, leading to disintegration in some form or other. This question was before me in a case where the process was used at a temperature of 900 degrees F., but experience showed that the parts stood up satisfactorily. Evidently any temperature limitation falls distinctly higher than this, but it would add to the value of the paper if Mr. Faris could say whether a definite limit has been established.

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Mr. T. H. Hill (Member): Although Mr. Faris makes no reference to it in the paper, it would be interesting to know if this process has been applied to the protection of propeller blades, which frequently suffer from erosion. A Clyde firm of steamship owners have coated cast steel and iron propeller blades with a mixture of tin and lead, which was formerly known as Johnston's patent. I have seen propeller blades which had been so treated, and after 20 years' service their surfaces were as smooth as glass, while propeller blades untreated have only lasted from four to five years. I feel quite confident that nickel-coated blades will maintain smooth surfaces which will not be seriously affected by erosion.

Mr. Faris refers to "perfect adhesion." The lack of that in some instances was the cause of failure in propellers which came under my notice. This may have been caused by an unsuitable temperature in coating the surfaces of cast-iron propellers. I do not know what the experience of others has been, but it may be of interest to them to know that the same company has, for almost 50 years, coated all their condenser tubes with tin, with the result that they have never experienced trouble with tubes. One ship, built in 1903, only had her condenser tubes renewed in 1923; that is to say, they lasted 20 years. Another ship had her tubes renewed in 1926 after 19 years' service, while in yet another vessel, built in 1893, the tubes lasted for 29 years. The two first vessels sailed to and from the Clyde, trading largely in estuary waters, and, according to the Corrosion Research Committee, such waters specially contribute to wasting or corrosion of condenser tubes. Tinning of the tubes has not been as widely applied as it might have been.

If the system of coating and making up worn parts by a nickel deposit is generally adopted, it will reduce the repair bill very considerably, and I feel there is a very wide field for its application.

Prof. W. Kerr, Ph.D., A.R.T.C. (Associate Member): Mr. Faris has made out a very sound case for the employment of nickel deposits; and from the wealth of evidence which he

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Prof. W. Kerr, Ph.D., A.R.T.C.
has submitted it would appear that the nickel coating endows the material with a high order of resistance to wear and corrosion in working operations. The successful results seem to be largely due to the "cold" process of deposition used. In an early sentence, Mr. Faris explains that the older methods of coating proved unreliable because of peeling of the deposit. But it might be submitted that these methods were really unsuitable in engineering applications because of a detrimental effect on the material itself. I recollect some discussion, years ago, regarding the plating of light steel springs by the usual process, which proved wholly unsuccessful. The steel became brittle, and fracture quickly ensued in use. Something of a mystery at the time, it would probably nowadays be looked upon as a case of penetration; and all attempts to coat metals by a hot process would probably raise that same question. Conversely, it might be supposed that a cold process would ensure safety in that respect. This might well be so, and the remarkable results of the adhesion tests quoted by Mr. Faris demonstrate the excellence of the amalgamation of the two materials. The "anchorage," as Mr. Faris expresses it, appears adequate and convincing. But is it not possible that this highly effective grip is of the order of an incipient intercrystalline penetration of the body metal by the coating metal, which, in no sense harmful in the cold condition, might possibly become a factor of influence in high-temperature work?

Mr. Faris describes the employment of nickel coatings in steam-turbine blading and nozzle partition plates. This is an application of great importance, and, if fully effective at all temperatures, of the highest prospective value. But I submit that there is no real proof in the paper that the coated materials are wholly reliable at high temperatures. High-temperature fractures are usually along the crystalline boundaries; and if the process of coating creates any initial tendency to intercrystalline penetration, the body metal may, thereby, be unduly weakened for the severe conditions of high-temperature work. In order adequately to judge the suitability of coated metals for such duties, it would be necessary to have

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Prof. W. Kerr, Ph.D., A.R.T.C.

the results of a reasonably comprehensive set of fatigue and other tests under high-temperature conditions, and I desire to ask Mr. Faris if any such information is available.

In conclusion, I would like to say that I have found Mr. Faris's paper of great interest, and impressive in its disclosure of the wide range of applicability of these nickelled materials. I congratulate Mr. Faris on the skilful way he has marshalled his evidence, and especially on the manner in which he has dealt with the technical aspects of a commercial process entirely free from any commercial bias.

Prof. Cecil H. Desch, F.R.S.: The methods of building up worn parts described in the paper have proved to be of high value, and deserve to be better known to engineers. I have seen examples of the work, and have made some experiments with objects treated in this way. There is one criticism which I wish to make. The adhesion tests described in the paper involve the pulling off of a ring of electro-deposited metal from a cylinder, although the details of the experiment differ. It is well known that electrolytic deposits, especially of nickel, are in a condition of tensile stress, so that a deposited ring is in much the same condition as if it had been shrunk on while hot. This stress has the effect of increasing the apparent adhesion. The only way to measure the true adhesion is that adopted by Ollard,* who deposited so large a mass at the end of a rod that the whole of the ring could be subsequently turned away, and a tensile test made in which the two metals were pulled apart by a tensile stress perpendicular to the plane surface of contact. Even with this test, to which no exception can be taken, the adhesion of nickel to iron is found to be of the order of the tensile strength of the metals, and portions are apt to be torn at the fracture. It is very remarkable that such high adhesion should be obtained, when it is considered that there is no interpenetration, the boundary between the two metals remaining quite sharp under the microscope.

* Trans. Faraday Soc., 1925, vol. 21, p. 81.

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Mr. T. Henry Turner, M.Sc.

Mr. T. Henry Turner, M.Sc.: The extended use of nickel deposits in engineering is to be heartily recommended, so long as the deposits are adherent under all service conditions and are substantial and workmanlike. Mr. Faris goes far in his paper to prove that these two conditions can be met by at least one process, and in so doing shows that such modern deposits are as different from ordinary cut-price, film-like, and porous nickel-plating as chalk is from cheese. Had this process been in existence during the war, many thousands of pounds and much time could have been saved by the reclamation of worn parts. Many of the points brought out by Mr. Faris are novel and of very real practical importance.

Mr. R. D. Moore, B.Sc. (President): Mr. Faris has put before us a most interesting and instructive paper showing how, by his process of nickel deposition, worn parts of machinery can be satisfactorily renewed, with great advantage to the engineer. He proves convincingly that the adhesion of the nickel to the material below it is absolutely sound. This method of making worn material good is useful, especially as has been pointed out, when the material might be distorted by the application of heat, such as is employed in the electro-welding process, which is equally applicable to renewals. Indeed, for the last 20 years, worn shafts and bearings have been economically and efficiently made good by the electro-welding process, in which the material applied is of the same quality as the original, and renewals are absolutely sound and good. Mention has been made of propeller blades, parts of which very soon get pitted through cavitation; a deposit of nickel on these parts would probably cure further trouble. I approve of rustless steel blades, but the price just now is prohibitive.

Mr. Faris: Several of the large number of the sleeves which were done for H.M. vessels, and to which Mr. MacNicoll refers, certainly showed surfaces which appeared to contain pit marks, but this was not a state of porosity.

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Mr. C. H. Faris.

Minute bubbles of hydrogen, liberated during the process, get trapped, and produce this effect, but such a condition has never been found to continue down to the steel upon which the nickel is imposed; thus the underlying surface is still protected. This condition is not so likely to occur on pieces such as valve parts, which have less superficial area, and in the very near future it is hoped that this slight trouble will be entirely eliminated.

On a valve of the size mentioned by Mr. MacNicoll, it would be unnecessary to have so heavy a deposit; the allowance for machining is far in excess of what would be required, and the final depth of deposit, on the completely finished part, would not require to be more than ·03 or ·04 inch. The hardness of the nickel surface and its immunity from the action of superheat would result in considerably less scoring; thus less frequent regrinding of the valve seats would be necessary, and the amount of regrinding would be less, each condition thus tending to conserve the depth of the nickel deposit. I may just mention that deposits of $\frac{1}{4}$ inch depth are quite possible, absolutely free from the slightest sign of the pitting to which Mr. MacNicoll refers. The difference between the coefficients of expansion of the two metals, nickel and steel, is so small that no difficulty has yet been experienced in that respect.

Mr. Wylie's remarks on plungers and glands are of much interest, and several theories might be advanced to account for the failure of the glands and neck rings. The circumstances would be far more serious had there been any defect with the plungers, but having recently had the opportunity of inspecting these plungers, through the courtesy of Mr. Wylie, I can quite confirm his statement that they are doing quite well, under fairly severe conditions.

The inspection of the rod which was immersed at half tide, off Dundee, was purely a visual one, and no heat was applied. That was at the end of 21 months' immersion, but when in Dundee a few days ago I found that the rod was still in the water, having been there now for over three years. The large

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Mr. C. H. Faris.
balanced valve parts, Figs. 12 and 13, to which Mr. Wylie refers, have not yet been in use long enough for a report to be made upon them.

I very much regret that I am not able to supply any details of the figures he asks for, but would again emphasise that the first cost of such work is not the most important factor, the two points to be considered jointly being the assured increased life, and the production cost compared with that when such parts are designed in stainless steel or other expensive alloys.

To the best of my knowledge, nickel deposited by this system has not been tried out under the conditions referred to by Mr. William Brown; it would need to be a matter of experiment.

In reply to Mr. Bonn, I may say that the test results given in the paper answer the question completely, as nickel-plating, as usually understood, has never been subjected to such severe tests, nor been applied to this class of work. The title of the paper necessarily confines my remarks to the uses, and I am sorry to have caused disappointment by the omission of details of the process itself; that subject would provide material for a separate paper.

I thank Mr. John S. Brown for his suggestion that points of historical interest might have been embodied in the paper, but my desire to concentrate on the uses and applications, believing these to be the more important and more directly bearing on the work of engineers and shipbuilders, resulted in such notes being omitted. His references to the iron deposition carried out during the war period are quite correct, and it was found that as the deposits were too soft for wear purposes, unless subsequent hardening operations were carried out, thereby introducing the risk of distortion, the method stood at a great disadvantage when nickel deposition became possible.

I am unable at the moment to give a definite figure of temperature limitation, as suggested by Mr. Brown, but when data from tests now going through are available, I shall be very pleased to communicate with him on that point. A

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Mr. C. H. Faris.

temperature of 800 degrees F. with superheated steam has no effect upon the adhesion of the deposit, and doubtless a much higher figure would be reached before the adhesion would be impaired. A specimen was heated in a furnace until it became a cherry red, and after cooling off in water the deposit was as firm as before. Another sample was cut through with an oxy-acetylene flame without the adhesion being impaired, but no figures are recorded of the temperatures reached.

It is of interest to learn of the long life of the condenser tubes referred to by Mr. Hill. I have been in touch recently with many superintendent engineers of shipping companies, and can assure him that their experience on this matter is not parallel with his statement, as they have met with much trouble, and are still looking for developments which will assure them of a tube possessing a longer life at a reasonable price. Brass condenser tubes protected in the bore by a nickel coating are now under test with several large shipping concerns, including Messrs. Furness, Withy & Co., and the Belfast-Liverpool steamer "Graphic" is also fitted with a number of such tubes.

It is particularly gratifying to hear from Prof. Kerr that he endorses the opinions stated in the paper as to the suitability of nickel-coated mild-steel parts, such as blading, nozzles, and valve parts, for steam-turbine work, and that he foresees a wider application in this direction. The point he raises regarding the high temperatures now ruling is an important one, and although past experience has shown that at 750 degrees F. the superheated steam has no effect upon the nickel surface, in view of yet higher temperatures being used, it would be advisable to endeavour to obtain figures showing at what temperature the adhesion between the two metals would be reduced.

Prof. Lea, of Sheffield University, informs me that experiments are proceeding along the lines indicated by Prof. Kerr, and it may be possible later on to form an opinion as to the temperature required to affect the adhesion of the nickel

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Mr. C. H. Faris.

deposit. Adhesion appears to be more a question of anchorage than penetration; thus the danger at increased temperatures to which Prof. Kerr points is hardly liable to be present. I can assure him, however, that in subsequent tests and research work these two very important points will be kept in mind.

The remarks of Prof. Desch are of very great interest indeed, and his statement that the adhesion is remarkable, when practically no interpenetration is present, is confirmed by the test referred to in the paper, at the foot of page 214, where it is recorded that a load of 24 tons per square inch failed to remove the steel core from the ring of nickel. After the punch had penetrated to a depth of $\frac{1}{32}$ inch it was withdrawn, the specimen cut and etched, and the resultant photomicrograph definitely showed the steel to be sheared, whilst a film of steel adhered to the inner surface of the ring of nickel. For the particulars of this test, I am indebted to Mr. A. T. Kersey, of the Royal Technical College, Salford.

In reply to the President's remark on the coating of stainless steel with nickel, I may state that although for special purposes this course has frequently been adopted, and the part rendered still less liable to corrosion, the majority of such cases have been worn or corroded components requiring reinforcing or building up to their original dimensions. On stainless steel, monel metal, and other special alloys, the welding of such parts presents difficulty.

The question of cost, though not dealt with in the paper, is an important one, but too much stress is often laid upon the first cost when considering the adoption of new methods. In numerous cases the old saying is true, that the increased life of the protected or built-up part will be remembered long after the first cost is forgotten. If a component worth, for example, £4 10s. when new, can be restored to its former standard size at a cost of about 35s., and then be capable of a life twice as long as its first life, it appears to be a commercial proposition. On very many parts the economy would be somewhat on those lines.

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RECENT DEVELOPMENTS OF THE EXHAUST-STEAM TURBINE.

By Dr. GUSTAV BAUER.

6th December, 1927.

INTRODUCTION.

THE undisputed advantages, in regard to the utilisation of heat energy, which have resulted from the introduction of the steam turbine, are due solely to the capacity of this prime mover to utilise the energy of the steam down to very low pressures. In this respect, the steam turbine is the opposite of the reciprocating piston-engine, in which the expansion of the steam, and, therefore, the utilisation of low pressures, is limited by the comparatively small volume of the low-pressure cylinder. At the higher pressures, however, the steam turbine has no advantages over the piston engine. The recognition of these two facts soon after the introduction of the steam turbine, led to the building of marine installations, in which the high pressures were utilised in piston engines and the low pressures in turbines, so called "exhaust turbines." Such installations, however, were only built for large powers. An example is that in the well-known "Olympic."

Until comparatively recent times the use of the exhaust turbine was limited to large ships, since it was considered necessary to give the exhaust turbine its own propeller shaft, which for the requirements of symmetry necessitated the provision of three or more shafts. Such a large number of propellers, however, is, of course, only justified in large vessels.

The idea of the exhaust turbine working on the same shaft as the piston engine was, as far as I know, like many brilliant

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ideas, first conceived by your illustrious countryman, Sir Charles Parsons. Evidently, however, Sir Charles or the Parsons Company did not realise the possibility of this idea, and, therefore, did not follow it up.

Experience in the manufacture of gearing, elastic couplings, and of vibration phenomena in rotary systems has, however, made possible the combination of the piston engine and the exhaust turbine on one propeller shaft, and it is the object of this paper to draw attention to a few features of such a combination.

Theory of the Steam Cycle in the Exhaust-Steam Turbine

The theoretical process in a steam plant can be, as is generally known, illustrated by the following cycle:—

The supply of heat to the boiler is first utilised for raising the temperature of the water in the boiler from the hot-well

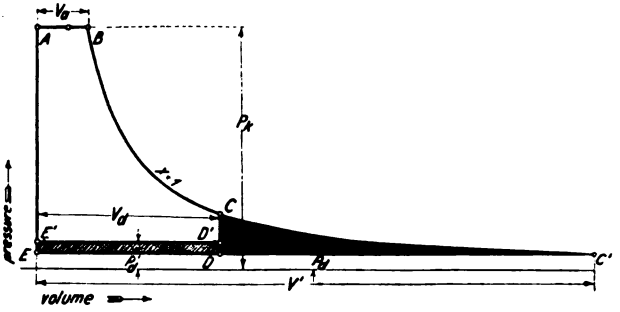

Fig. 1.

temperature to the boiler temperature, then for evaporating the heated water at constant pressure and constant temperature, or, in other words, for converting the water into steam. This process, shown in Figs. 1 and 2, is followed first by adiabatic expansion at constant entropy (neither addition nor subtraction of heat from an outside source) in the steam engine, thus lowering the steam temperature, and finally by abstraction of heat at constant temperature in the condenser.

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Fig. 1 is the pressure-volume, and Fig. 2 the temperature-entropy diagram.

The lines EA and *ea* in Figs. 1 and 2 show the process of heating the water in the boiler, during which its temperature and pressure are raised. E is the condenser pressure and *e*

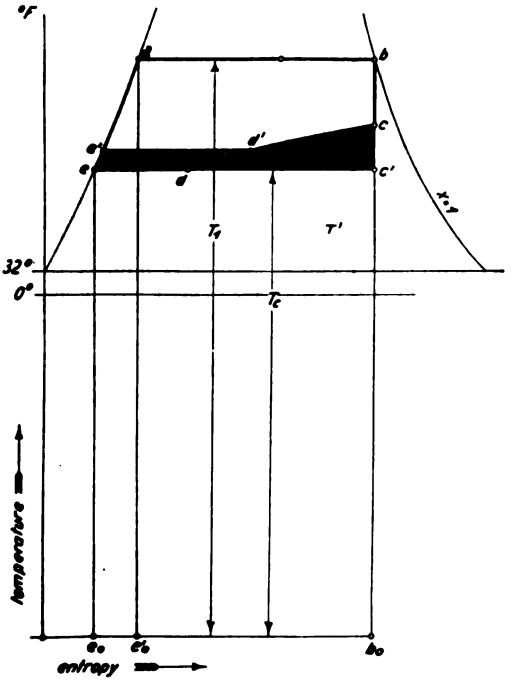

Fig. 2.

the condenser temperature, A the steam pressure and *a* the steam temperature in the boiler. The horizontal lines AB and *ab* show the heat quantity necessary for evaporating the heated water, whereby the specific steam quantity of zero at the points A and *a* is increased to 100 per cent. in points B and *b*. The curves BC′ and *bc′* show the expansion from the boiler pressure B and boiler temperature *b* down to the condenser pressure C′

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and temperature c'. The lengths C'E and $c'e$ show the abstraction of heat at constant pressure and temperature in the condenser, whereby the end volume of the steam at the points C' and c' is approximately reduced to zero; that is to say, to the volume of the water.

As the size of L.P. cylinders cannot for practical reasons be increased beyond a very limited diameter, it is not possible to attain unlimited expansion in a piston engine. Even in those types where weight and space are least limited, namely, piston engines for merchant vessels, it is not possible to increase the expansion ratio beyond 14 times the volume of the H.P. cylinder, although the adiabatic expansion of saturated steam from 16 atmospheres (227 lbs. per square inch absolute) down to 93 per cent. vacuum (27⅞ inches) causes an increase of volume of 163 times.

The piston engine, therefore, is, as is generally known, very much inferior to the steam turbine with regard to utilisation of the expansive properties of the steam, as in the latter the steam can attain the velocity which corresponds to complete expansion. Therefore, the losses in the steam turbine are limited to the small percentage caused by the practical limits of exhaust areas.

Figs. 1 and 2 give a simple means of estimating the losses in the piston engine, which can be eliminated by adding an exhaust turbine. Assuming that the L.P. cylinder of a steam engine, for practical reasons, cannot have a larger volume than V_d, Fig. 1, the expansion must be arrested at the points C and c respectively, Figs. 1 and 2, which means that from these points a pressure-drop to the condenser pressure p'_d takes place. The lines CD and cd respectively show this pressure-drop during exhaustion of the L.P. cylinder. Of the theoretical working area EABC' and $eabc'$ respectively, the triangular areas CC'D and *cc'd marked in black are lost*, and these could theoretically be regained by the addition of an exhaust turbine. The exhaust turbine, however, brings another gain, as may now be explained.

On account of the impossibility of giving the exhaust valves

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and ports of the L.P. cylinder sufficiently large areas, throttling losses occur during the flow of the steam from the L.P. cylinder to the condenser which are, as a rule, very considerable. If the pressure in the L.P. cylinder during the exhaust period is p'_d, Fig. 1, instead of the condenser pressure p_d, a theoretical loss corresponding to the areas EE'D'D and $cc'd'd$ occurs. These areas are shown hatched in Figs. 1 and 2. This loss is also eliminated by the addition of an exhaust turbine, as on account of its large exhaust areas there is no appreciable pressure difference between the last blade row and the condenser.

These two principal advantages of the exhaust turbine can be readily appreciated from Figs. 1 and 2 of the theoretical process in a steam plant. *The energy corresponding to the sum of the areas shown in black, and hatched, represents the possible gain due to the exhaust turbine.* Beyond these, however, the exhaust turbine brings a further gain, which is by no means negligible. The inlet pressure to the turbine must correspond to the points C and c, Figs. 1 and 2, in order that the above-named advantages may be completely realised. This increase of back pressure, however, in the L.P. cylinder causes a decrease of the temperature differences in it, and, therefore, of the condensation losses.

Generally speaking, the initial pressure in exhaust-steam turbines is taken at ·5 atmosphere (7·11 lbs. per square inch absolute), which corresponds to a steam temperature of 81° C. (178° F.). The steam, therefore, leaves the L.P. cylinder of the piston engine with an exhaust turbine at a temperature of 81° C. (178° F.), while without the exhaust turbine, condenser pressures and temperatures exist at this point. Assuming the vacuum in the condenser to be 85 per cent., 25·4 inches of mercury, the steam temperature would be 54° C. (129° F.), and, further, assuming that the steam enters the L.P. cylinder with a pressure of 1·5 atmosphere (21·33 lbs. per square inch absolute), which corresponds to a temperature of saturated steam of 111° C. (232° F.), the L.P. cylinder of a piston engine without exhaust turbine would have a temperature-drop of

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57° C. (135° F.), and with an exhaust turbine a drop of 30° C. (86° F.) only.

As seen from the above, much larger power losses must take place in the L.P. cylinder in a piston engine without exhaust turbine, as the temperature difference is 57° C. (135° F.), while by the addition of an exhaust turbine it is only 30° C. (86° F.).

The theoretical gain due to the addition of the exhaust turbine in a specific example is as follows (see Fig. 1):—

Live-steam pressure p_k -	15 atmospheres (213 lbs. per square inch absolute)
Specific steam quantity x - - - - - - - - - -	0·97
Condenser pressure p_d -	·05 atmosphere (0·71 lb. per square inch absolute)
Exhaust pressure of L.P. cylinder p'_d	·12 atmosphere (1·71 lb. per square inch absolute)
Mean piston speed - - - - - -	4 m. per sec. (787 ft. per minute)
Cut-off volumes of H.P. cylinder V_h - -	1 cubic m. (35·32 cubic ft.)
Cut-off volumes of L.P. cylinder V_d - - -	12 cubic m. (424 cubic ft.)

The total expansion of the engine is, therefore, twelvefold.

Assuming that 1 kg. (2·21 lbs.) of steam goes through the cycle every second, the theoretical output of the piston engine *alone* is = E′ABCD′, Fig. 1, = 138·8 calories (551 B.Th.U's.) = 790 i.h.p., and the theoretical output of the piston engine *with* exhaust turbine is EABC′, Fig. 1, = 192 calories (762 B.Th.U's.) = 1,092 i.h.p.

The gain in output in percentage of the piston engine is:—

$$\frac{\text{EABC}' - \text{E}'\text{ABCD}'}{\text{E}'\text{ABCD}'} = \frac{1{,}092 - 790}{790} = 38{\cdot}4 \text{ per cent.}$$

Of course, this figure is influenced by the fact that both the actual piston engine and the piston engine with exhaust turbine have deficiencies which prevent them from attaining the theoretical output. However, it may here be mentioned that these only slightly influence the gain which can actually be achieved by the addition of the exhaust turbine. The losses in the actual piston engine alone, and the piston engine with exhaust turbine, are best illustrated in the heat-entropy (Mollier) diagram, in which the converted heat is the ordinate and the entropy values the abscissæ.

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Calculation of a Piston Engine to which an Exhaust Turbine is to be Added.

The piston engine *alone* will first be considered in relation to the heat-entropy diagram, Fig. 5, and then the same engine *with* exhaust turbine, as this makes it possible to see at once the advantages resulting from the addition of the latter. As an example, the piston engines of the high-class twin-screw passenger ship "Cap Norte" and her sister ship "Antonio Delfino" may be taken. They belong to the well-known Hamburg-Sudamerikanische Dampfschifffahrts-Gesellschaft; each has a deadweight capacity of 9,080 tons, and has been fitted with an exhaust turbine with great success.

Fig. 3 shows the general arrangement of the piston engine and exhaust-turbine installation in these ships. The exhaust-steam turbine with its gearing is illustrated by the thick lines. The constructive details of exhaust-turbine installations will be dealt with later.

The dimensions of the piston engines of these ships are:—

Diameter of the H.P. cylinder	680 mm. (26·8 inches)
Diameter of the I.P. cylinder	1,100 mm. (43·3 inches)
Diameter of the L.P. cylinder	1,800 mm. (70·9 inches)
Stroke	1,300 mm. (51·2 inches)
Revolutions per minute	80
Steam pressure in boiler	15 atmospheres (213 lb. per square inch absolute)
Temperature in boiler	300°C. (572°F.)
Superheat	103°C. (217°F.)

With the engine plants of both ships exhaustive tests were made, on the "Cap Norte" before and after installation of the exhaust turbines, and on the "Antonio Delfino" after installation. The steam process of both ships is, therefore, known in all its details. The mean results of the indicator diagrams of both plants are shown in Fig. 4, in which the dotted lines apply to the conditions before addition of the exhaust turbine, and the continuous lines to those after. Of course, the indicator diagrams taken before and after addition of the exhaust turbines are both based on the same cut-offs. The fitting of exhaust

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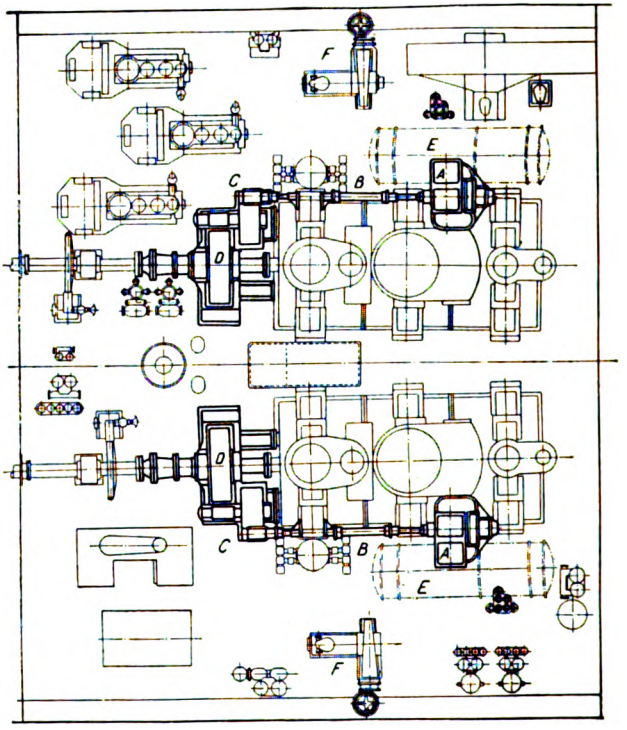
turbines gave an increase of speed of one knot, *i.e.*, from 14 to 15 knots.



S.S. "Cap Norte," "Antonio Delfino"
General Arrangement of Piston Engines and Exhaust-Turbines
Total Horsepower 8100 IHP

A Exhaust Turbine
B Connecting Shaft
C First Reduction Gear and Hydraulic Clutch
D Main Wheel with second Reduction
E Condenser
F Circulating Pump

Fig. 3.

Let us first examine the dotted lines, which, as has been mentioned, apply to the engines *before addition of the exhaust turbine*, and consider the process shown by these lines in

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the heat-entropy diagram, Fig. 5. The initial pressure in the H.P. cylinder is shown in the indicator diagram, Fig. 4, to be 15·2 atmospheres (216 lbs. per square inch absolute). As back pressure in the H.P. cylinder, the mean value of its exhaust-pressure line may be taken, which is here 5·2

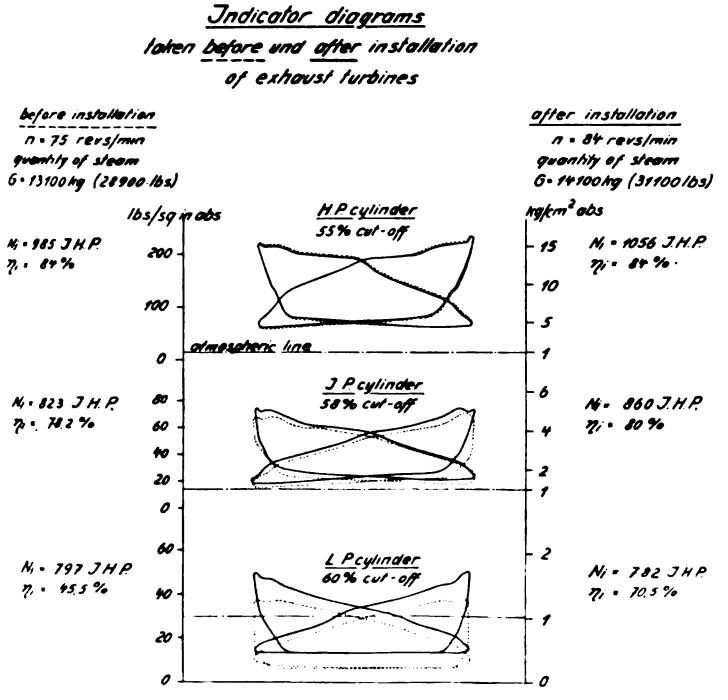

Fig. 4.

atmospheres (74 lbs. per square inch absolute). The temperature of the superheated steam on entering the cylinder was found to be 290° C. (554° F.). At adiabatic expansion from this point, which is shown in the heat-entropy diagram, Fig. 5, by the letter A, down to the above-mentioned back pressure, we get as the theoretical end-condition in the H.P. cylinder the point B. This adiabatic heat-drop $h = 56{\cdot}5$ WE (224 B.Th.U's.)

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corresponds to an output in the H.P. cylinder of $\frac{G \cdot h}{632}$, where G is the quantity of steam working in the engine. This was found by measuring the quantity of condensate to be G = 13,100 kg. per hour (28,900 lbs. per hour), so that the

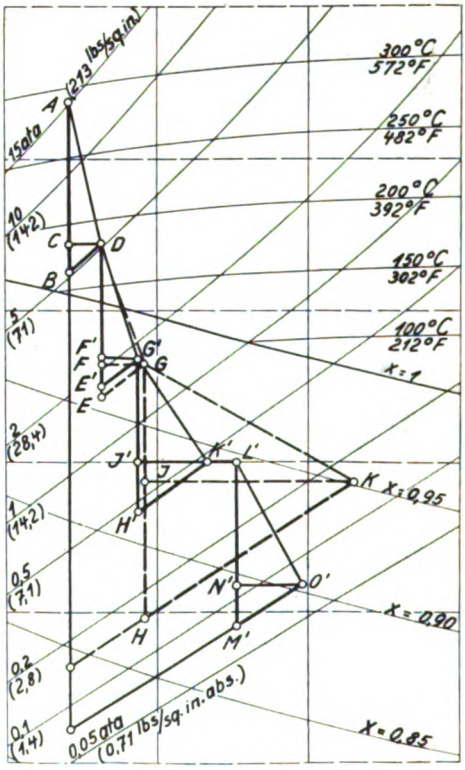

Fig. 5.

theoretical output of the H.P. cylinder would be 1,172 h.p. Against this theoretical output, the indicator diagram, Fig. 4, shows an indicated output of 985 i.h.p., so that the efficiency of the H.P. cylinder is $\eta_H = 84$ per cent. The part of the adiabatic (theoretical) heat-drop AB, which is actually converted into work in the H.P. cylinder is, therefore, only

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$h_i = 0{\cdot}84 \,.\, h = 47{\cdot}5$ WE (188·5 B.Th.U's.). The difference between the *adiabatic heat-drop* h (AB) and that calculated from the indicator diagram *(indicated heat-drop)* h_i, may be regarded as resulting from turbulence, condensation, and friction. These losses are partially regained in the following cylinders.

It is usual to show what has been regained by subtracting the partial heat-drop corresponding to these losses, in this case 9 WE (36 B.Th.U's.), from the whole adiabatic heat-drop AB. These losses are shown by the line BC, so that we attain the point C, Fig. 5. On the other hand, this point must lie on the line of the back pressure passing through point B; that is to say, on the line of 5·2 atmospheres (74 lbs. per square inch absolute). Therefore, we get the end condition in the H.P. cylinder by drawing a horizontal line from C to the point D; and the process is the same as if we had only utilised the indicated heat-drop h_i (AC in Fig. 5) in the H.P. cylinder and attained the line of back pressure by throttling (constant heat of generation).

This end condition D of the H.P. cylinder is taken to be the initial condition in the I.P. cylinder. In order to make this assumption permissible, the mean of the exhaust-pressure line (back pressure) of the H.P. cylinder has been brought into conformity with the mean initial pressure in the I.P. cylinder.

Proceeding with the I.P. cylinder in the same manner as with the H.P. cylinder, by assuming its back-pressure line to be the mean of its exhaust line, in this case 1·6 atmosphere (22·8 lbs. per square inch absolute), then from the end condition D, Fig. 5, in the H.P. cylinder, the vertical line of the adiabatic heat-drop is drawn down to the back-pressure point E, thereby finding the adiabatic (theoretical) heat-drop in the I.P. cylinder to be $h = 50{\cdot}8$ WE (202 B.Th.U's.). The indicated heat-drop from the indicator diagram, Fig. 4, calculated in exactly the same way as before, gives 823 i.h.p., and, therefore, an indicated heat-drop of $h_i = 39{\cdot}7$ WE (157 B.Th.U's.). The efficiency of the I.P. cylinder is thus $\eta_i = 78{\cdot}2$ per cent.;

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the heat-drop utilised is shown by the line DF, Fig. 5, and the final condition in the I.P. cylinder by the point G.

As in the case of the I.P. cylinder, this point is taken as the initial condition in the L.P. cylinder, whose end condition is shown in point H. It lies on the line of the condenser pressure $p_k = 0{\cdot}15$ atmosphere (2·13 lbs. per square inch absolute). We have, therefore, made the L.P. cylinder responsible for the total flow losses between it and the condenser, and thus get the adiabatic (theoretical) heat-drop to be 84·6 WE (336 B.Th.U's.). As the output of the L.P. cylinder, according to the indicator diagram, Fig. 4, is 797 h.p., a heat-drop of 38·5 WE (153 B.Th.U's.) has been doing work, which means that the efficiency of the L.P. cylinder is $\eta_L = 45{\cdot}5$ per cent. The end condition in this cylinder is obtained by drawing the horizontal line from the point J up to its intersection at K with the line of the condenser pressure.

From the total output shown by the three indicator diagrams, Fig. 4, which is 2,605 i.h.p., from the total adiabatic (theoretical) heat-drop between the initial condition in the H.P. cylinder and final condition in the condenser, Fig. 5, and from the total steam quantity consumed, which was 13,100 kg. per hour (28,900 lbs. per hour), we get the thermal efficiency of the whole piston engine to be $\eta = \frac{G \cdot h}{N_i \cdot 632} = 67{\cdot}1$ per cent., and the specific steam consumption to be 5·03 kg. per i.h.p. (11·08 lbs. per i.h.p.).

Calculation of the Same Piston Engine After Addition of the Exhaust Turbine.

We now proceed to consider the process *after the installation of the exhaust turbine*, and, as before, examine the thick-lined indicator diagram in the heat-entropy (Mollier) diagram. As already mentioned, the cut-offs are the same as before, so that the exhaust turbine increases the output, and, therefore, also the revolutions from 75 to 84 r.p.m. The quantity of steam entering the H.P. cylinder per unit of time is also increased in

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proportion, in the present case from 13,100 kg. (28,900 lbs.) to 14,100 kg. (31,100 lbs.) per hour. The calculation must, therefore, be based on this steam quantity.

The initial pressure in the H.P. cylinder is the same as before, and also the back pressure. There is, therefore, the same adiabatic (theoretical) expansion in the H.P. cylinder, namely, from A to B. Assuming an efficiency of 84 per cent., the same as before the addition of the exhaust turbine, we find the point C and also the point D. This gives the end condition of the H.P. cylinder, which is the same as before. The output of the H.P. cylinder is, however, increased to 1,056 i.h.p., corresponding to the larger steam quantity and higher r.p.m.

The back pressure in the I.P. cylinder, as seen from the indicator diagram, Fig. 4, has, however, increased to a mean of 1·7 atmosphere (24·2 lbs. per square inch absolute). Correspondingly its adiabatic (theoretical) heat-drop is somewhat smaller than before, namely, 48·2 WE (191·5 B.Th.U's.). Consequently the adiabatic expansion in the I.P. cylinder only reaches to the point E′, Fig. 5. An increase of efficiency, therefore, takes place as shown by the indicator diagram, Fig 4, which gives 860 i.h.p., corresponding to a thermal efficiency of 80 per cent. By taking the corresponding indicated heat-drop down from the point D in Fig. 5, the point F′ is determined; and as the end condition of the I.P. cylinder we find the point G′.

The back pressure in the L.P. cylinder is found to be 0·45 atmosphere (16·5 inches). The adiabatic (theoretical) heat-drop is, therefore, shown by the vertical line G′H′, Fig. 5, and amounts to 49·6 WE (197 B.Th.U's.). The indicator diagram, Fig. 4, shows the indicated output to be 782 i.h.p. Therefore, the efficiency of the L.P. cylinder is much higher than before, namely, 70·5 per cent. By taking the corresponding indicated heat-drop in Fig. 5, which is 35 WE (139 B.Th.U's.) from the point G′ down to the point J′, and drawing a horizontal line from this point to the back-pressure line, 0·45 atmosphere (16·5 inches), the end condition of the piston engine is found to be the point K′.

Through the exhaust steam oil-separator, the changeover

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valve, and the strainer, certain throttling losses occur between the L.P. cylinder and the turbine. In the present case these cause a pressure-drop from the above-mentioned back pressure of the L.P. cylinder, namely, 0·45 atmosphere (16·5 inches) to a pressure of 0·38 atmosphere (18·6 inches), before entering the turbine. This condition is shown in Fig. 5 by the point L′.

According to measurements, the vacuum at exhaust from the turbine was 92½ per cent., which corresponds to an absolute pressure of 0·075 atmosphere (27¾ inches). The adiabatic (theoretical) heat-drop at the disposal of the exhaust-steam turbine is shown by the line L′M′ in Fig. 5, and is 54·2 WE (215 B.Th.U's.). From torsion-indicator measurements on the tunnel shaft of the output of the piston engine with turbine, the output of the turbine was calculated to be 800 s.h.p., the thermal efficiency to be 71 per cent., and the heat-drop $h_i = 38{\cdot}5$ WE (152·5 B.Th.U's.), which corresponds to the line L′N′ in Fig. 5. The total efficiency of the turbine, including 3 per cent. loss in the hydraulic coupling, and 4 per cent. loss in the gearing is, therefore, 66 per cent.

In order to find the output of the turbine, which would correspond to the indicated output of a piston engine, divide the above effective output of 800 s.h.p. by the mechanical efficiency of the piston engine of this size. As in the present case this was found to be 89·5 per cent.; then the indicated output of the turbine is 892 i.h.p., and the corresponding indicated heat-drop $h_i = 40$ WE (159 B.Th.U's.). The so-called total indicated output of the piston engine plus the exhaust turbine is, therefore, 3,590 i.h.p., and the gain in output, at the same cut-off as before, 38 per cent.

As the specific steam consumption is $\frac{14{,}100}{3{,}590} = 3{\cdot}93$ kg. per i.h.p. per hour (8·67 lbs. per i.h.p. per hour), the addition of the exhaust turbine has produced *a saving in steam consumption of 22 per cent.* In order to find the *saving in fuel consumption*, the extra consumption of the auxiliaries, which is about 3 per cent., must be subtracted from the above-mentioned figure.

In order to get the increase in output *at the same steam con-*

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sumption as before the addition of the exhaust turbine, it is only necessary to calculate the total i.h.p. of 3,590 on the basis of the steam quantity used before the addition. We thus get $3{,}590 \times \frac{13{,}100}{14{,}100} = 3{,}335$ i.h.p. As the i.h.p. without the exhaust turbine was 2,605, the increase of output at the same steam consumption is 28 per cent. From this figure would also have to be subtracted the extra steam consumption of the auxiliaries in order to get the saving in fuel consumption. This would, therefore, be about 25 per cent.

Process for Calculating New Exhaust-Turbine Plants.

The calculation of the possible increase in output of an existing engine by the addition of an exhaust turbine would be as follows:—

The basis for this calculation is given by the indicator diagrams of the steam engine, which, in nearly all cases, can be procured from the shipowner. These show, among other matters, the cut-off and the initial pressure in the H.P. cylinder. The steam consumption of the existing piston engine will, however, generally not be known exactly, as unfortunately such measurements are only rarely made during a trial trip or on service. Generally speaking, the steam consumption of the existing piston engine has to be estimated from experience with plants of similar size and working conditions.

Having got thus far, it will be necessary to find the vacuum available for the exhaust turbine. At this point it will have to be decided whether or not steps should be taken to increase the vacuum. This point will be dealt with later.

Now comes the question of initial pressure of the exhaust turbine. It will preferably be made equal to the pressure existing at the end of the expansion period in the L.P. cylinder. As a pressure-drop generally takes place after the end of the expansion period, this assumption means reducing the output of the L.P. cylinder. However, this amount is generally very small, because, as has already been shown, the efficiency of

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the L.P. cylinder is increased by the addition of the exhaust turbine. According to the foregoing, therefore, the initial pressure of the exhaust turbine generally lies between 0·4 and 0·5 atmosphere (5·7 to 7·1 lbs. per square inch absolute).

In order to acquire an idea of the conditions, this process might be examined in the heat-entropy (Mollier) diagram. The steam conditions of the H.P. and I.P. cylinders are given by their indicator diagrams. The adiabatic expansion in the L.P. cylinder, on the other hand, ends at a pressure equal to the initial pressure of the exhaust turbine plus 0·05 to 0·07 atmosphere (0·71 to 1·0 lb. per square inch absolute), due to the losses in the piping and apparatus between the L.P. cylinder and the turbine. The adiabatic expansion in the exhaust turbine, however, reaches from the pressure of 0·4 to 0·5 atmosphere (5·7 to 7·1 lbs. per square inch absolute) down to the condenser pressure. The question of the efficiency of the L.P. cylinder and the turbine has already been treated, so that all the elements for estimating the total output now exist.

I should here like to remark that, in order to make the pressure drop between the L.P. cylinder and the turbine as small as possible, it is necessary to provide large exhaust bends in which the steam velocity is not more than from 40 to 60 m. per second (131 to 197 ft. per second).

An uncertain factor in these calculations is, as is readily seen, the estimation of the steam consumption of the existing engine. However, in none of the ships converted to date has the estimate been found to be much in error. It can, therefore, be said that, with the increasing number of ships fitted with exhaust turbines, any uneasiness on account of the uncertainty of this figure vanishes.

If a case be now taken in which no increase in output *but a saving in fuel consumption* is aimed at, the method already described can be utilised to calculate the steam quantity required for attaining the same output as before the addition of the exhaust turbine.

With regard to the possible increase of output in the H.P. cylinder at the same cut-off as before the addition of the exhaust

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turbine, it may here be remarked that contractions are sometimes found in the steam channels of the H.P. cylinder, which, when the revolutions are increased by the exhaust turbine, cause a large increase in the throttle losses. In such cases an increase in revolutions is not accompanied by a corresponding increase in the steam quantity entering the H.P. cylinder.

Possible Increase in Output or Saving in Fuel by the Exhaust Turbine.

From the foregoing discussion of the theoretical process, it is evident that the possible gain through adding an exhaust

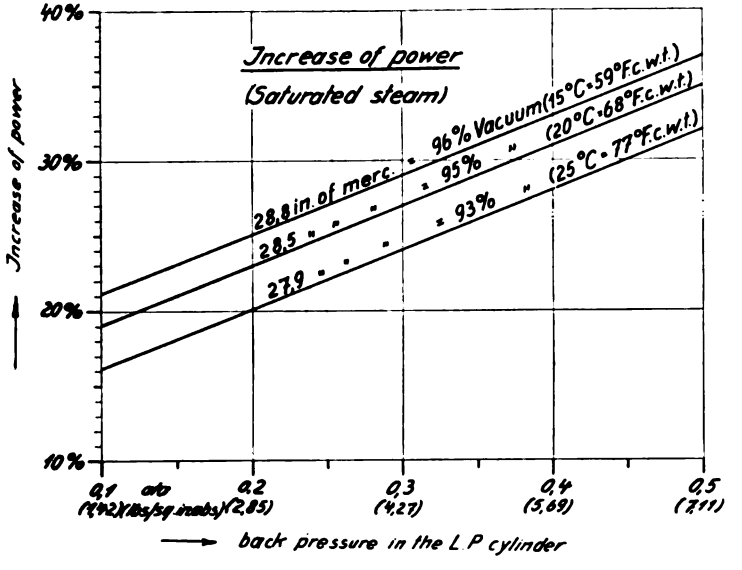

Fig. 6.

turbine to an existing piston engine is the greater, the less economical the heat process of the piston engine is; that is to say, the higher the back pressure of the L.P. cylinder, the higher the end pressure of expansion in the L.P. cylinder, or, in other words, the higher its overload, the better the possible vacuum.

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Consequently the percentage of gain is greater in a saturated-steam engine, and also greater in engines with low boiler-pressure than in those with very high boiler-pressures, or superheat.

This is shown with the nearest approximation to actual conditions—especially for medium expansion end pressures

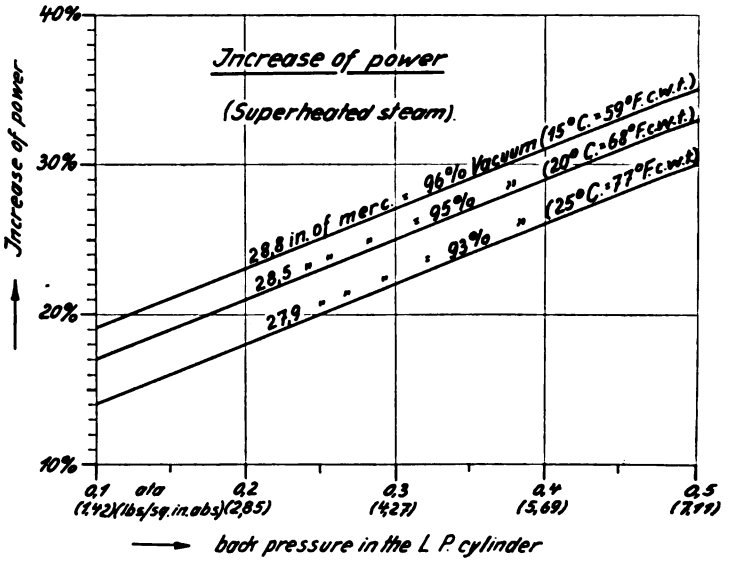

Fig. 7.

in the L.P. cylinder—by Figs. 6, 7, 8, and 9. Figs. 6 and 7 show the percentage of power increase at the same steam consumption as before, by the addition of an exhaust turbine, while Figs. 8 and 9 show the percentage of steam saved at the same power as before. Figs. 6 and 8 apply to saturated steam, and Figs. 7 and 9 to superheated-steam installations. In all four illustrations, the ordinates show the percentage of power increase or saving in steam consumption of the existing piston engine for the vacua obtainable at the various sea-water temperatures, while the abscissæ show the corresponding back pressures in the L.P. cylinder.

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The inclusion of the vacua obtainable at various sea-water temperatures, enables the gains in power or saving in steam

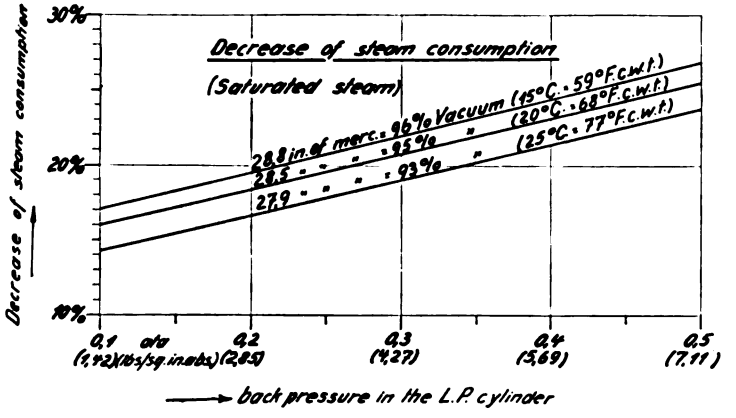
Decrease of steam consumption
(Saturated steam)
28,8 in. of merc. = 96% Vacuum (15°C. = 59°F.C.W.T.)
28,5 " " " = 95% " (20°C. = 68°F.C.W.T.)
27,9 " " " = 93% " (25°C. = 77°F.C.W.T.)
30%
20%
10%
Decrease of steam consumption
0,1 ata (1,42)(lbs/sq.inch)(2,85)
0,2 (2,85)
0,3 (4,27)
0,4 (5,69)
0,5 (7,11)
back pressure in the L.P. cylinder

Fig. 8.

consumption, for the various world routes, to be estimated. Later on I will go into this matter more fully. The vacua are

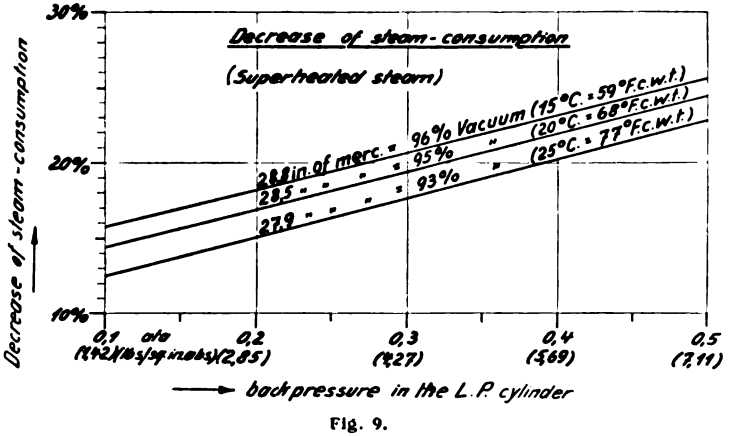

Fig. 9.

further based on a condenser rating of from 30 to 40 kg. of steam per square m. (6·14 to 8·18 lbs. per square ft.) of condenser cooling-surface, and a sea-water quantity of from 70 to

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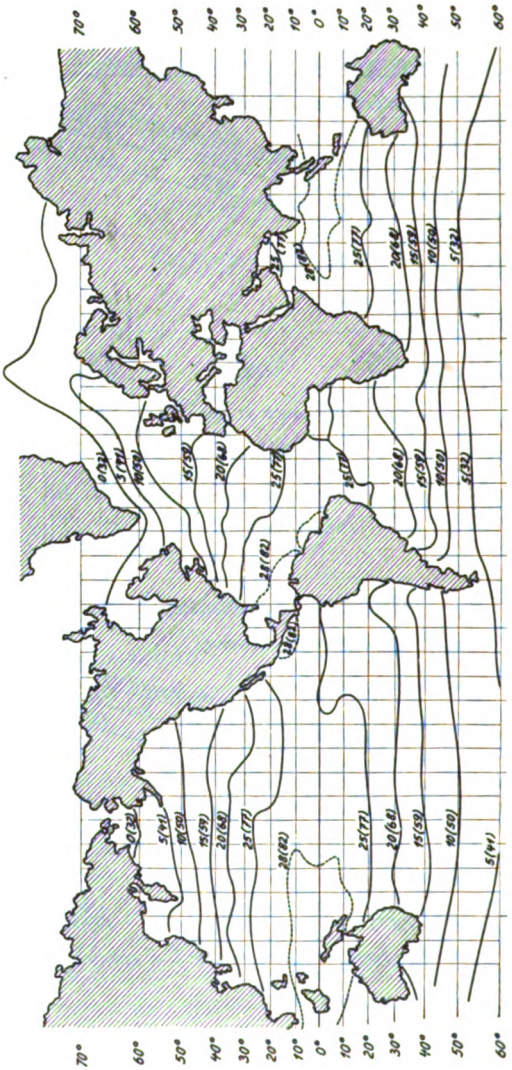

Fig. 10.

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80 times the quantity of steam consumed by the piston engine with an exhaust turbine. The larger figure applies to the higher sea-water temperature.

Fig. 6 shows, for example, that for a piston engine working with saturated steam, a back pressure in the L.P. cylinder of 0·35 atmosphere (4·975 lbs. per square inch absolute), and a mean sea-water temperature of 22° C. (72° F.), which corresponds to 94 per cent. vacuum (28·2 inches), a power increase of 28 per cent. is to be expected by the addition of an exhaust turbine. The conditions as given by the above figures are very general, and, therefore, cannot be regarded as exceptionally favourable to the exhaust turbine. In a large number of cases the back pressure in the L.P. cylinder of the piston engine will be about 0·2 atmosphere (2·85 lbs. per square inch absolute), and the vacuum obtainable 95 per cent. (28½ inches), which corresponds to a mean sea-water temperature of 20° C. (68° F.), so that, according to Fig. 6, a power increase of 23 per cent., through the addition of an exhaust turbine, can be guaranteed. In a plant working with superheated steam, the power gain in the above-mentioned case would be 21 per cent.

Sea-Water Temperatures on the Ocean Surface in Various Parts of the World.

The sea-water temperatures of the various ordinary steamer routes are not without interest in connection with the exhaust turbine question. On the map, Fig. 10, the mean yearly isotherms of the larger ocean surfaces are given, and the mean cooling-water temperature for a given steamer route during the whole year is shown.

The results for several ordinary routes are given in Table I, from which it will be seen that, although the sea-water temperatures are very different in various parts of the world, the mean temperature of longer journeys is fairly constant. This fact has been proved by the excellent results obtained by steamers running between Hamburg and the river Plate.

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TABLE I.

MEAN COOLING-WATER TEMPERATURES FOR DIFFERENT STEAMER ROUTES.

ROUTE.	°C.	°F.
London-New York - - -	13·7	56·7
London-Buenos Aires - -	20·3	68·6
London-Sydney, via Suez - -	20·8	69·5
London-Sydney, via Capetown -	17·0	62·6
London-Jamaica - - -	22·6	72·7
Liverpool-Montreal - - -	10·2	50·4
Oslo-New York - - - -	10·8	51·5
Vancouver-Yokohama - -	13·8	56·9
Vancouver-Sydney - - -	23·1	73·6

DESCRIPTION OF A TYPICAL EXHAUST-TURBINE INSTALLATION FOR AN EXISTING PISTON ENGINE.

In passing from the theoretical discussion of the subject to a consideration of a typical exhaust-turbine plant of the Bauer-

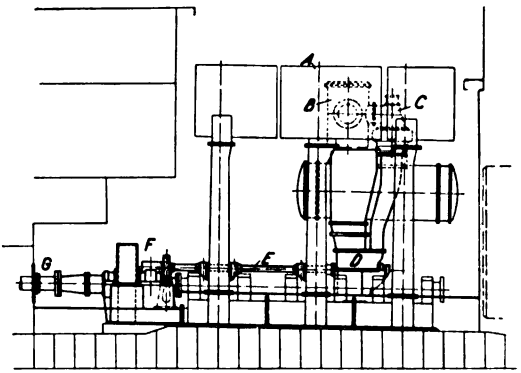

Fig. 11.

Wach system, I will take as an example an exhaust-turbine installation at present under manufacture in one of the yards

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of the Deutsche Schiff- und Maschinenbau Aktiengesellschaft, for a 9,500 tons deadweight freight-ship.

The cylinder diameters of the triple-expansion engines of this ship are respectively 800 × 1,330 × 2,140 mm. (31·5 × 52·4 × 84·3 inches), the stroke 1,520 mm. (60 inches), the boiler pressure 16 atmospheres (228 lbs. per square inch absolute), the steam temperature at the superheated outlet is 350° C. (662° F.), and the revolutions 72 per minute. The present output is 4,400 i.h.p.; after the addition of the exhaust turbine it will be about 5,400 i.h.p.

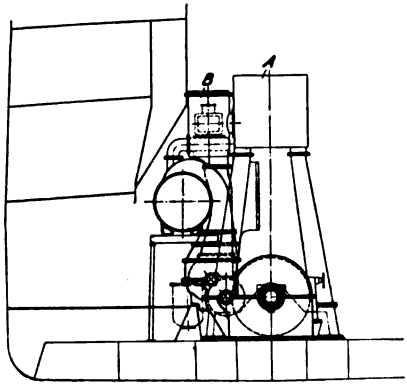

Fig. 12.

Figs. 11 to 13 show the existing piston engine with the new exhaust-turbine installation. From the L.P. cylinder A, the steam flows through the exhaust steam oil-separator B and the changeover valve C to the exhaust turbine D. The output of the turbine is transmitted by the intermediate shaft E to the gear box F, which is connected to the propeller shaft G. During manœuvring the turbine is cut out by means which will be explained later, and the steam from the L.P. cylinder flows directly to the condenser through the changeover valve C, since during manœuvring and going astern, the existing piston engine only is working.

The details of the exhaust-turbine plant are shown in Figs.

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14 and 15. Here the turbine D, which is of the Parsons reaction type and runs at 3,065 r.p.m., is shown in section. The exhaust turbine D drives the pinion H by the comparatively low transmission shaft E, which, of course, must be so stiff and well supported that whirling is eliminated. The pinion H meshes with the gear wheel J of the first reduction. The pinion K of the second reduction, which meshes with the main gear wheel L, is connected to the intermediate gear wheel J by the hydraulic Vulcan coupling O_1O_2. The main gear wheel L is keyed to the shaft R, which again is connected by the intermediate piece T to the propeller shaft G.

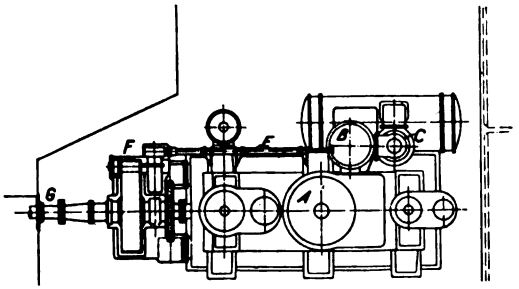

Fig. 13.

The Vulcan coupling is constructed according to the principle first used by Prof. Föttinger. It consists of the halves O_1 and O_2, containing a number of simple radial and axial blades dividing each half into a number of cells, which are filled with lubricating oil. The transmission efficiency of the coupling is from 97 to 98 per cent.; that is to say, the difference in revolutions between the driving part O_1 and the driven part O_2 is from 2 to 3 per cent. Between the two parts O_1 and O_2 there is a clearance of from 10 to 15 mm. ($\frac{3}{8}$ to $\frac{5}{8}$ inch). The coupling has a two-fold purpose, firstly, to enable the even turning turbine and the uneven turning piston-engine to work together, so that any unevenness of the turning-moment is not transmitted; secondly, to permit of an instantaneous cut-out of the exhaust

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turbine. This is done by the ring N, which, by being moved axially, permits the oil in the coupling to be thrown out through the holes in the circumference of the driving half O_1, so that the connection between the first reduction and the pinion K is at once broken. For reconnection, it is only necessary to close the holes by moving back the ring N to its working position and filling the coupling with oil through the piping M. Emptying and filling of the Vulcan coupling can be carried out in a very short time.

As seen from Figs. 14 and 15, the details of the gearing are as follows:—The driving half O_1 of the coupling is built into the intermediate gear wheel J, and this gear wheel is keyed to the shaft P, which is supported in the journals Q_1 and Q_2. The driven half O_2 is keyed to the hollow shaft carrying the pinion K of the second reduction, whilst this shaft is supported in two bearings—one beside the coupling half O_2, and the other beside Q_2. The support of the coupling halves with their gear wheels and pinions is, therefore, very rigid.

The main gear wheel L is not connected directly to the propeller shaft, but keyed to the hollow shaft R, which is supported in the large and rigid bearings S_1 and S_2. The crankshaft of the piston engine and hollow shaft R are connected by the long intermediate shaft V and the intermediate piece T, which is fixed to the shaft R by the cone U. The intermediate shaft V carries the single disc thrust-block, which consists of the collar W and the bearing X. For disconnecting the whole exhaust-turbine plant from the piston engine, it is only necessary to remove the flange bolts which connect the hollow shaft R with the intermediate piece T.

The main object of the arrangement incorporated in the hollow shaft R and the intermediate shaft V, is to eliminate from the main gear wheel the shocks of the piston engine, occasioned by the motion of the reciprocating parts, which are especially heavy when the main engine bearing at Y may be worn down. In this arrangement, the intermediate shaft V can move vertically, relatively to the hollow

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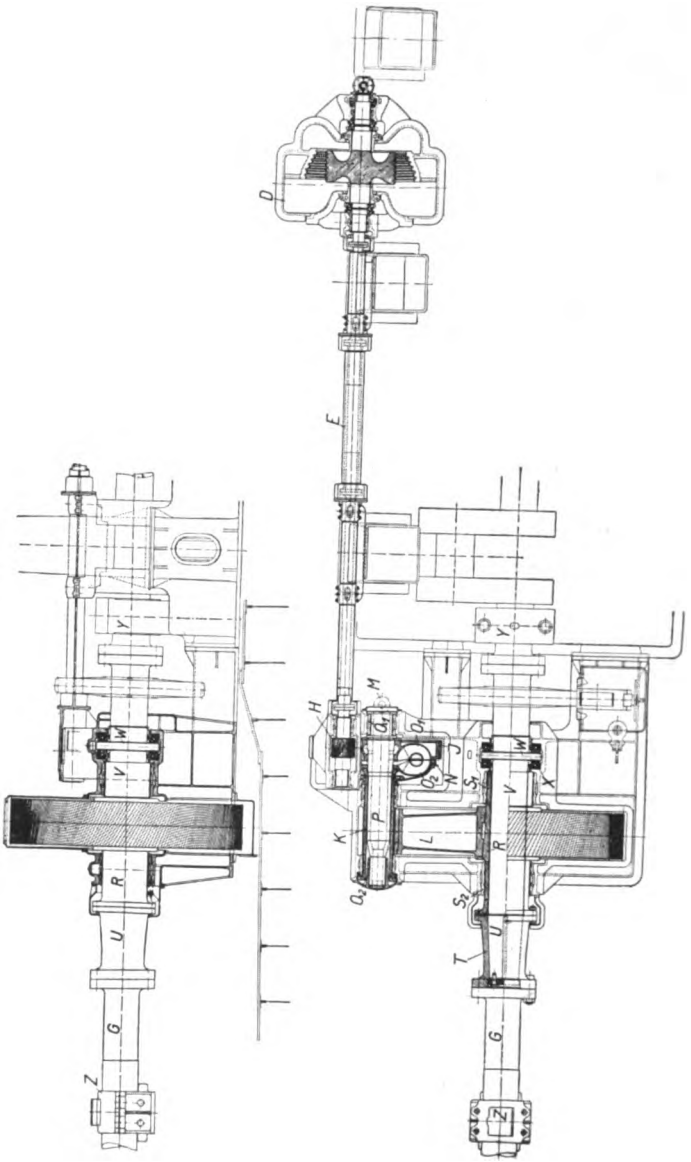

Figs. 14 and 15.

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shaft R, without detrimental effect to the bearings of the main gear wheel L. The intermediate shaft V is made long, so that, in the event of the main bearing Y having a play of 1 mm. ($\frac{1}{25}$ inch) over its whole circumference, the bending forces set up at U are only slight. It must be taken into account that the distance between the intermediate shaft V and the foremost bearing Z of the propeller shafting increases the ease of deformation of the intermediate shaft V, and, therefore, decreases the forces set up at U. The arrangement of the hollow shaft R and the intermediate shaft V has given excellent results in practice, as none of the many ships already fitted with exhaust-turbine installations has shown the slightest difficulties with any of the gear wheels or pinions.

As previously remarked, the turbine is cut out when the piston engine is running astern. As the only purpose of the exhaust turbine is to increase the output of the piston engine or to decrease its fuel consumption during unimpeded steaming periods, the piston engine alone will generally be used in harbours and narrow waters.

The Control Gear of the Vulcan Hydraulic Coupling.

As already mentioned, the exhaust turbine is disconnected from the piston engine by emptying the hydraulic coupling through opening the holes in the circumference of the driving part O_1, Fig. 15, by means of the ring N, and reconnected by filling the coupling with oil, by means of a pump, after having closed the holes. In order to prevent racing of the exhaust turbine, before emptying the coupling, the steam from the L.P. cylinder must be cut off from the turbine and led directly to the condenser. This operation is effected either by a change-over valve or by a system of flaps.

In the installation, Figs. 11 to 15, the cutting off of the steam supply to the exhaust turbine is effected by the change-over valve shown in detail in Fig. 16. The passage C of this valve to the exhaust turbine is opened by oil under pressure, working on the auxiliary piston E, and closed by a strong

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spring L acting on this piston, so that in the case of the oil pressure falling away, the passage to the exhaust turbine is closed and the passage to the condenser opened. As the ring N, Fig. 15, is also worked by oil pressure, it is easy so to interconnect the exhaust turbine and hydraulic coupling that the

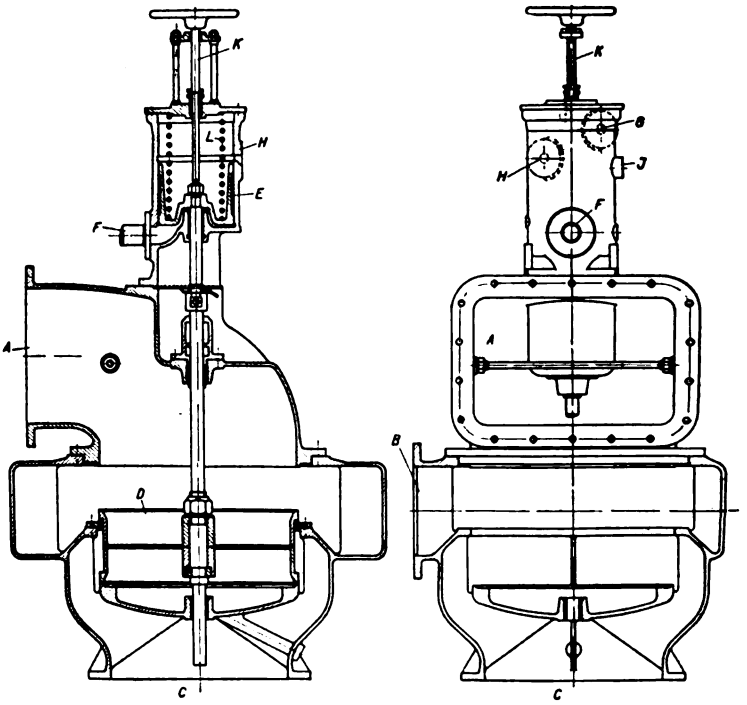

Fig. 16.

former cannot be put into action if the latter is not completely filled. It is unnecessary here to go into details of this arrangement, but it may, however, be mentioned that, should the exhaust turbine race for any reason, the safety governor of the turbine relieves the pressure on the auxiliary piston E, Fig. 16, and thus closes the steam passage C to the exhaust turbine.

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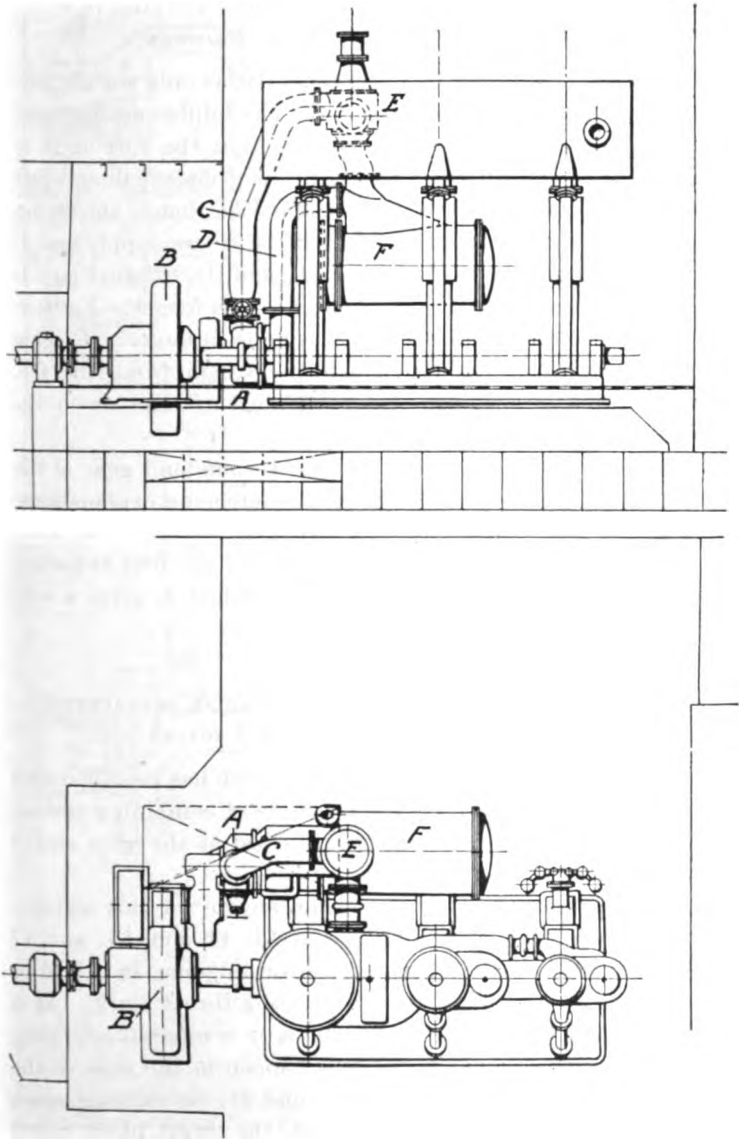

Figs. 17 and 18.

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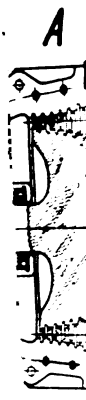
Another Example of Exhaust-Turbine Installation for New or Existing Piston Engines.



The installation shown in Figs. 17 and 18 is only slightly different from that already described; the chief difference between it and that shown in Figs. 11 to 13 is that the turbine A is placed further aft, so that there is no long intermediate shaft between it and the gear box B. On the other hand, the piping is somewhat more complicated, in that the steam supply pipe C from the L.P. cylinder to the turbine A, and the exhaust pipe D from the turbine to the condenser F, are both longer. Further, the required space aft of the piston engine is larger. E again is the changeover valve by which the steam from the L.P. cylinder is either switched to the exhaust turbine or to the condenser F.

Fig. 19 shows a section through the turbine and gear of the installation, Figs. 17 and 18. From the foregoing explanations, the construction will be easily understood. As will be seen, the long shaft H between the gear wheel of the first reduction and the primary part of the hydraulic coupling J, gives a very elastic connection between these two parts.

A Further Example of an Exhaust-Turbine Installation for Existing or New Piston Engines.

The design shown in Figs. 20 and 21, which has been installed in several ships, is based on the principle of combining turbine and gearing in a compact aggregate, placed at the after end of the piston engine.

The space required aft of the piston engine for this installation and those shown in Figs. 11 to 13, 14 and 15, and 17 and 18 is, in the case of existing piston engines, in whole or in part, provided by removing the existing thrust block. As it is generally of the multicollar type, it is comparatively long. Should, however, as will sometimes happen in the case of the installations, Figs. 17 and 18, and 20 and 21, the existing space aft of the piston engine be insufficient, the thrust block recess must be enlarged. Generally this presents no difficulty.

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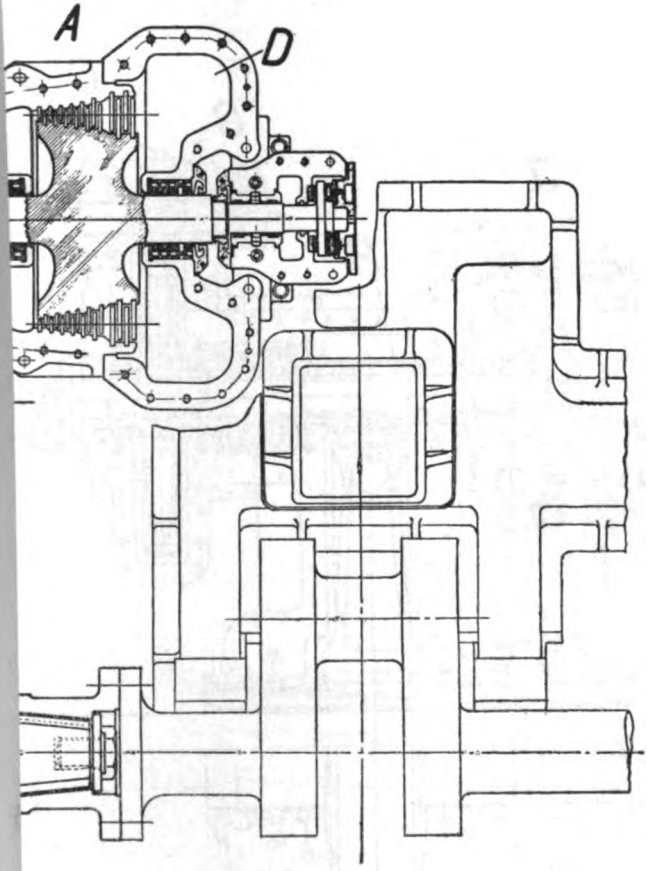

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Another Example of Exhaust-Turbine Installation for New or Existing Piston Engines.

The installation shown in Figs. 17 and 18 is only slightly different from that already described; the chief difference between it and that shown in Figs. 11 to 13 is that the turbine A is placed further aft, so that there is no long intermediate shaft between it and the gear box B. On the other hand, the piping is somewhat more complicated, in that the steam supply pipe C from the L.P. cylinder to the turbine A, and the exhaust pipe D from the turbine to the condenser F, are both longer. Further, the required space aft of the piston engine is larger. E again is the changeover valve by which the steam from the L.P. cylinder is either switched to the exhaust turbine or to the condenser F.

Fig. 19 shows a section through the turbine and gear of the installation, Figs. 17 and 18. From the foregoing explanations, the construction will be easily understood. As will be seen, the long shaft H between the gear wheel of the first reduction and the primary part of the hydraulic coupling J, gives a very elastic connection between these two parts.

A Further Example of an Exhaust-Turbine Installation for Existing or New Piston Engines.

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e L.P.
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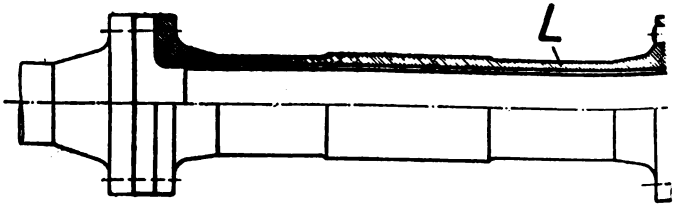

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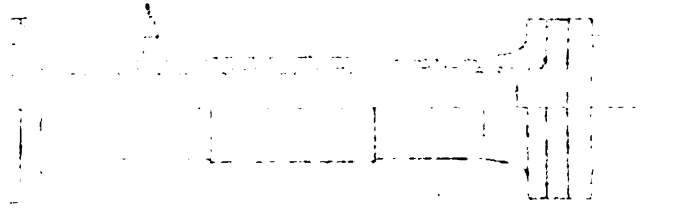
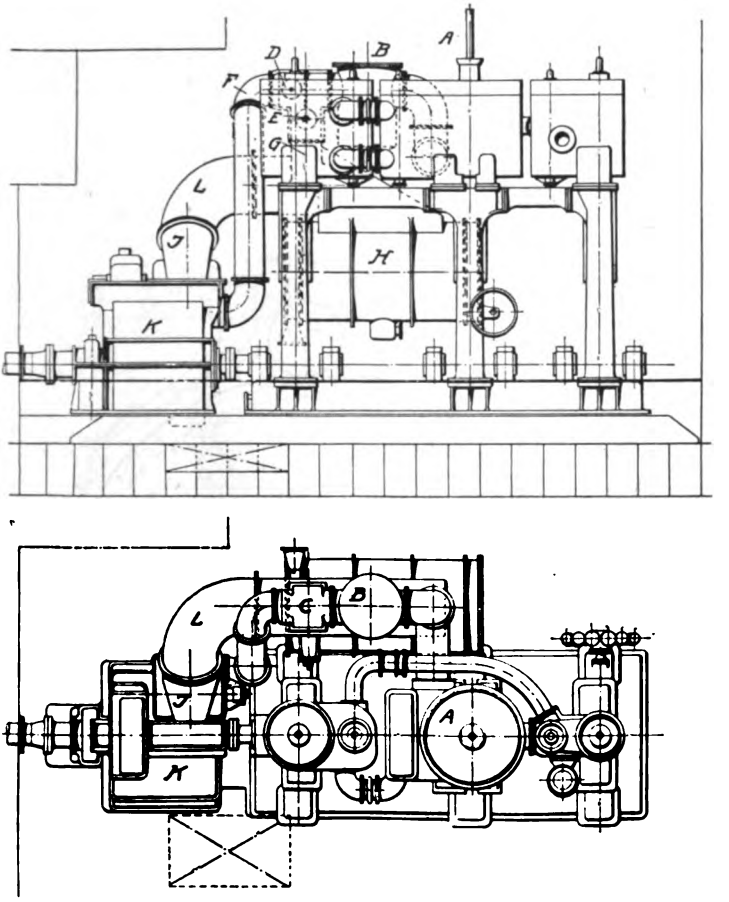


As seen from Figs. 20 and 21, the steam from the L.P. cylinder A first enters the exhaust steam oil-separator B, then



Figs. 20 and 21.

passes either to the exhaust turbine J or to the condenser H, through the flap box C, containing the two flaps D and E. These are so coupled together that, if the flap D is open, the flap E is closed, and *vice versa*. In the case of D being open,

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the steam passes to the exhaust turbine J, and if E is open, to the condenser H. The casing of the exhaust turbine J and

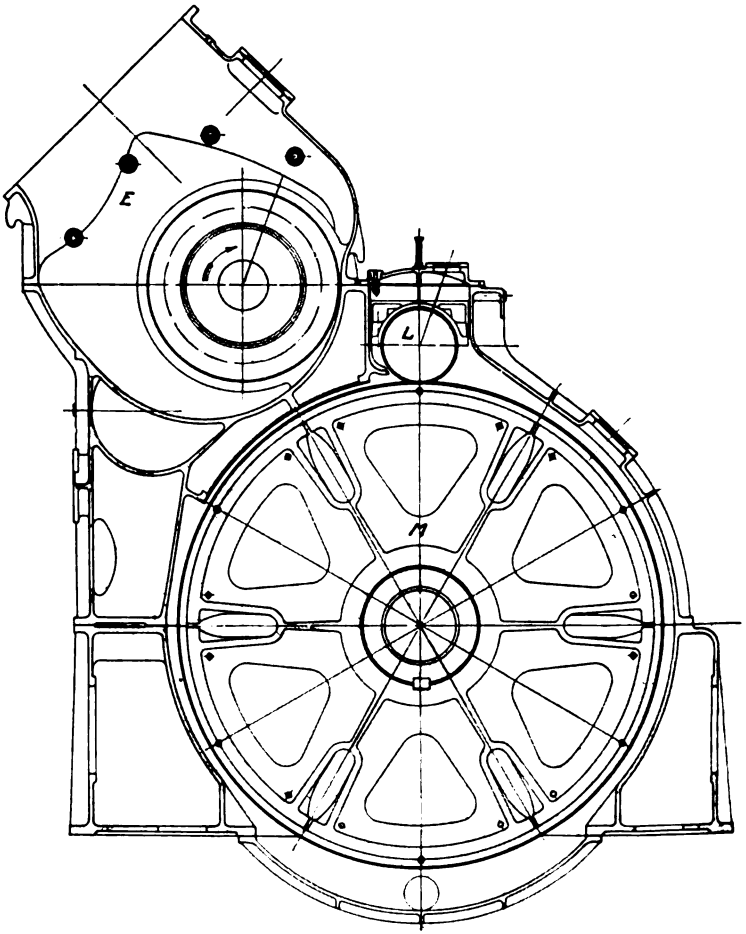

Fig. 23.

the gear case form a single unit K. The exhaust steam from the turbine flows to the condenser through the exhaust bend L.

Details of the exhaust turbine and gearing are shown in the

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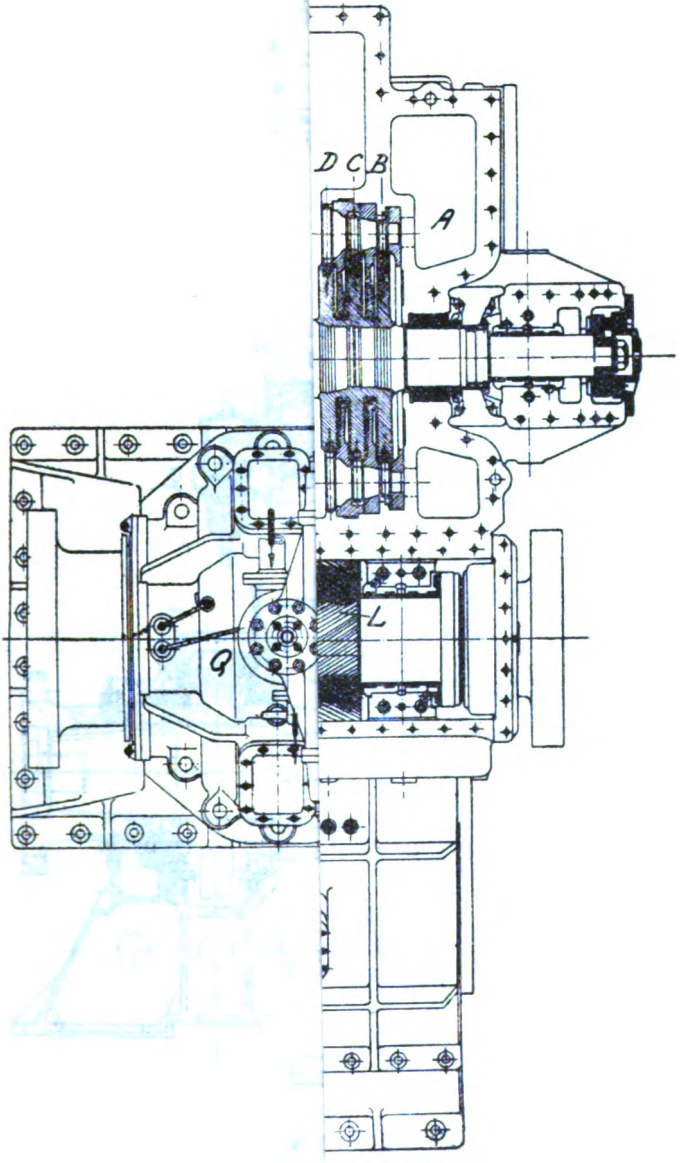

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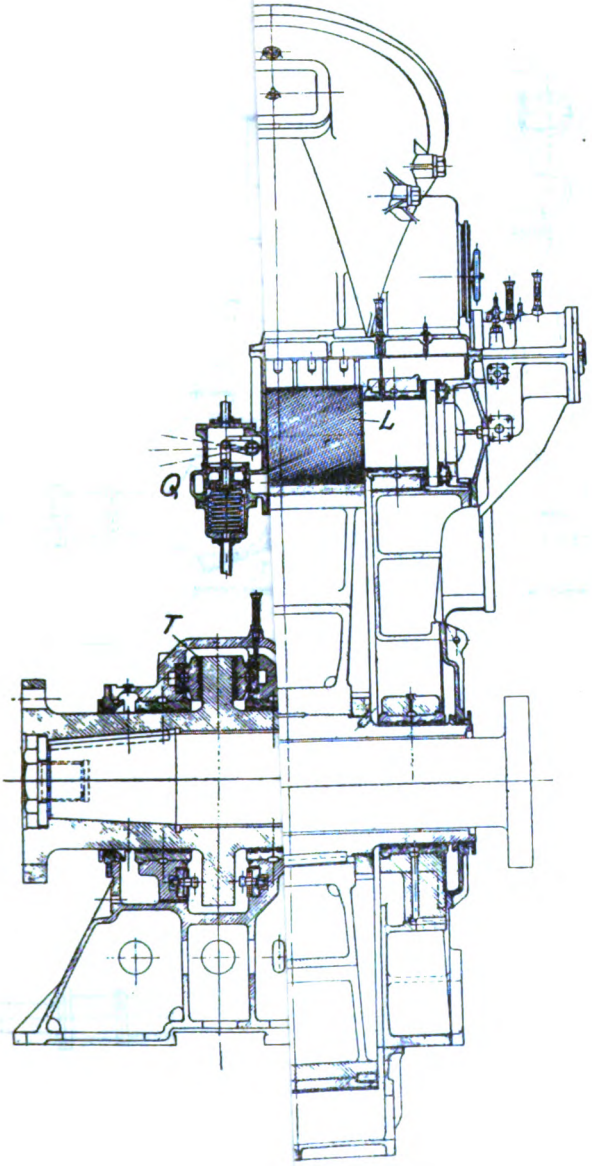

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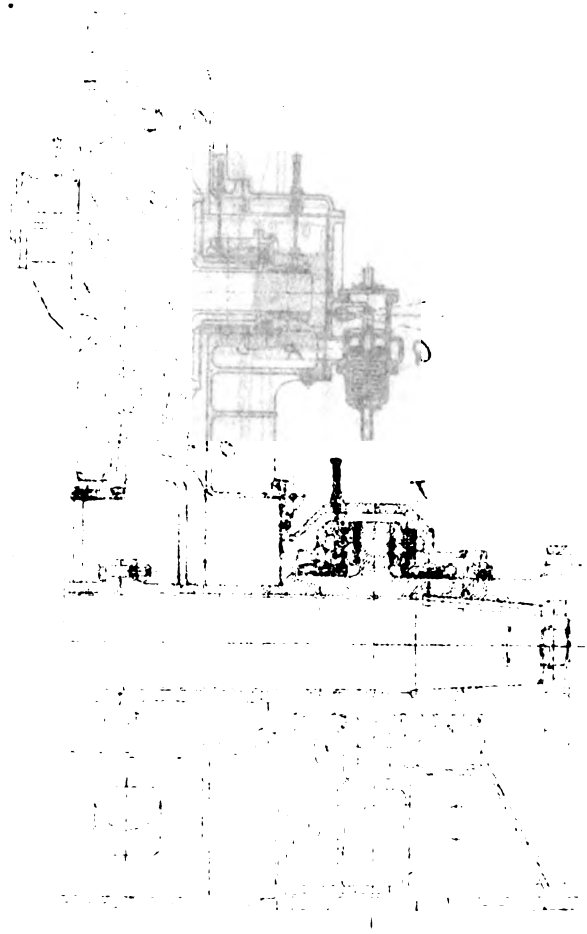

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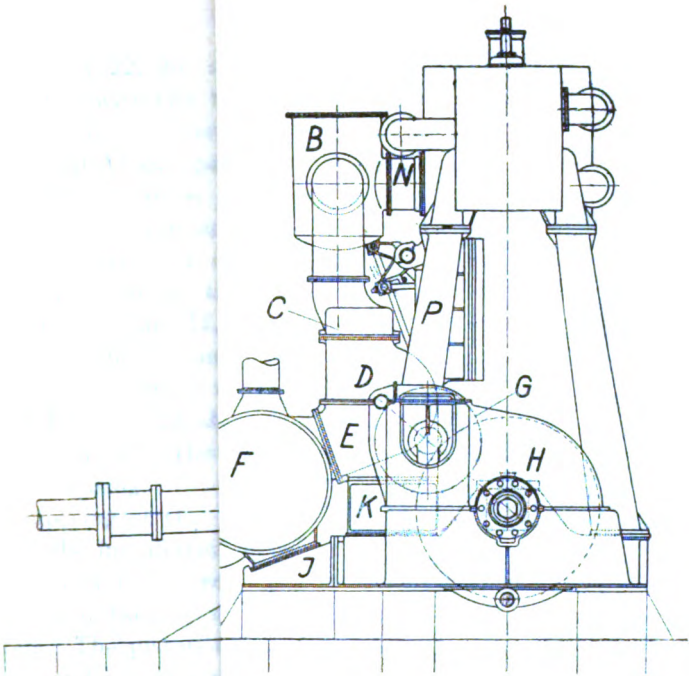

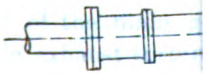

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three Figs. 22, 23, and 24. Fig. 22 shows the exhaust turbine in section with the top casing removed. As seen, it is a double-flow turbine. Steam enters each turbine half through the nozzles at A, and passes through the impulse wheels B, C, and D to the common exhaust space E, and thence to the condenser. The pinion F of the first reduction is fixed to the turbine shaft, and drives the gear wheel G (see also Fig. 24), into which, as in the installation shown in Figs. 14 and 15, the primary part H, Fig. 24, of the hydraulic Vulcan coupling is built. The secondary part J of the coupling is connected to the main pinion L, which drives the main gear wheel M by the shaft K. Fig. 23 shows the main gear wheel M and pinion L in section, also the connection between the gear casing and turbine casing.

Emptying of the Vulcan coupling is not effected by a ring, as in the installation Figs. 14 and 15, but by pistons N distributed over its circumference and fixed to a common ring O, which is worked by a servomotor Q by means of rods and elbow levers. The piston of the servomotor Q is worked by oil pressure, and a spring acts on the piston in such a manner that the holes in the circumference of the coupling are closed in the event of the oil pressure falling away. Therefore, even if this happens, the turbine is connected to the gearing, and is thus under load. The servomotor also controls the filling of the coupling and the changeover valve.

I believe from what has already been said, and from Figs. 22, 23, and 24, that the details will be appreciated. I may mention that in this case also, as in the installation shown in Figs. 13 to 15, by removing the bolts connecting the hollow shaft of the main gear wheel to the intermediate shaft, the whole exhaust-turbine installation can be cut out.

A Design of an Exhaust-Turbine Installation Recommended for New Piston Engines.

Such an installation is shown in Figs. 25, 26, and 27, and from what has already been said its construction will easily be

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understood. The arrangement is as follows:—The exhaust turbine DE is mounted on a cast-iron stool K bolted to the bedplate of the piston engine, and situated between its two aft back-columns P and Q. The condenser F lies below the turbine, and rests on an inclined stool J, also bolted to the bedplate of the piston engine. The changeover box C, containing the flaps

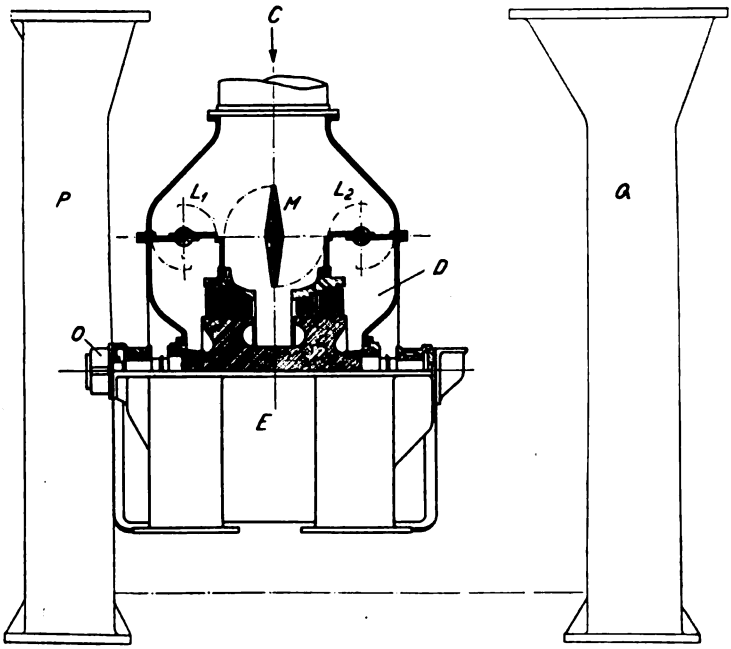

Fig. 28.

L_1, L_2, and M, Fig. 28, is mounted on the top of the casing D, and connected to the exhaust steam oil-separator B, which is fixed to the L.P. cylinder A by the pipe N. As in the installation shown in Figs. 20 and 21, the flaps L_1, L_2, and M are so connected to each other that, when the flaps L_1 and L_2 are open, the flap M is closed, and *vice versa*. The flap M controls the admission of the steam to the exhaust turbine, and the flaps L_1 and L_2 to the condenser. The exhaust turbine DE is of the

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Parsons reaction type, as in the installation shown in Figs. 14 and 15, and the arrangement of gearing and coupling is the same. Turbine DE and gear box GH are connected by the intermediate shaft O. The output of the installation shown in Figs. 25, 26, and 27 being comparatively large, 6,500 i.h.p. for the combined piston engine and turbine, the exhaust turbine is of the double-flow type, as seen from Fig. 28.

As the exhaust turbine lies near to the L.P. cylinder, and as the condenser is directly connected to it, the passage of the steam from this cylinder through the turbine to the condenser is short, and, therefore, the flow losses small. As, further, the condenser lies below the exhaust turbine, any water collecting in the latter is at once drained off. Finally, the exhaust turbine is housed within the outlines of the reciprocating engine, so that the space required aft of the piston engine is comparatively small.

Selection of the Arrangement on an Exhaust-Turbine Installation.

From the various examples of actual installations already given, it will be evident that, within the limits of the type of plant, several different arrangements of exhaust turbine and gear box, relatively to each other and to the piston engine, are possible.

The installations illustrated and described all refer to triple-expansion engines with three cylinders of comparatively large powers, but, of course, any of the arrangements can be adapted to any existing or new form of piston engine with any number of cylinders. For smaller powers, say, under 1,000 i.h.p., simplified designs are being developed.

Improvement of the Turning-Moment of the Reciprocating Engine.

It is essential that the addition of an exhaust turbine to an existing piston engine should not necessitate a renewal of the propeller shaft, as this would make the conver-

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S.S. „Antonio Delfino", „Cap Norte."

Torque diagrams

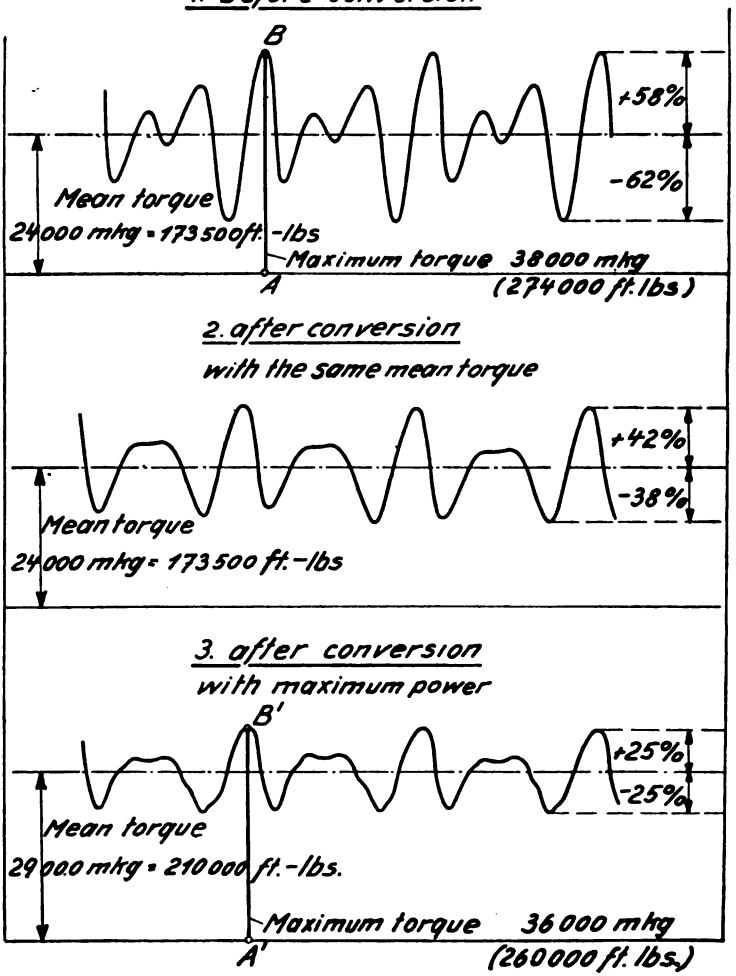

Fig. 29.

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sion too expensive. Fortunately in all the many conversions carried out up till now, or under construction, the calculations of the various classification societies and other authorities have all led to retention of the existing shafting.

The reason for this is as follows:—Firstly, as the turning-moment of a turbine is entirely even, the addition of an exhaust turbine to a piston engine very materially decreases the unevenness of its turning-moment, so that the total turning-moment of piston engine and exhaust turbine is much more even than that of the piston engine alone. Secondly, the evenness of the turning-moment of the piston engine and exhaust turbine is further increased by the fly-wheel effect of the main gear wheel, the gear wheel of first reduction with the hydraulic coupling, and the exhaust-turbine rotor. In consequence of the high rate of revolutions of the latter parts, their fly-wheel effect is especially great. A large number of torsionmeter measurements made before and after the addition of exhaust turbines have verified this.

Fig. 29 shows torsionmeter diagrams taken before and after the addition of exhaust turbines to the twin-screw freight and passenger ships "Antonio Delfino" and "Cap Norte." From these it will be seen that, in spite of an increase of output of 33 per cent. by the exhaust turbine, the maximum torque *before* its addition, line AB (1), is greater than the maximum torque, line A′B′ (3), *after* its addition. The line AB represents a maximum torque of 38,000 m.kg. (274,000 ft.-lbs.), and corresponds to 82·6 propeller r.p.m. and 2,845 b.h.p. of the piston engine alone, whilst the line A′B′ represents a maximum torque of 36,000 m.kg. (260,000 ft.-lbs.), and corresponds to 89·1 propeller r.p.m. and 3,680 b.h.p. of piston engine and turbine. That the increased evenness of the torque, shown in the decrease of its variations from a mean of 60 per cent. to a mean of 25 per cent., is not a result of the increase in revolutions, is seen from the torsionmeter diagram under (2), Fig. 29, which was taken at the same output and same revolutions as before the addition of the exhaust turbine. The mean torque is, therefore, the same, namely, 24,000 m.kg. (173,500

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ft.-lbs.). Its variations are, however, only plus 42 per cent. and minus 38 per cent., against plus 58 per cent. and minus 62 per cent., Fig. 29 (1), which corresponds to a decrease of the maximum torque of from 38,000 m.kg. (274,000 ft.-lbs.) to 34,000 m.kg. (246,000 ft.-lbs.), Fig. 29 (2).

The Sequence of Operations During the Switching In and Out of the Exhaust Turbine.

The switching-in of the exhaust turbine is effected by an oil-worked control gear. In the curves shown in Fig. 30, the abscissæ represent time in seconds and the ordinates the pressures of the steam entering the turbine, and the revolutions. The dotted curve shows the path of the changeover valve during the switching-in period, starting from its bottom position (steam flowing to condenser) up to its top position (steam flowing to turbine). The continuous line shows the corresponding revolutions of the turbine, and the chain-dotted line the initial steam pressures. At the beginning of the switching-in period the turbine is still spinning uncoupled from the last manœuvre; its revolutions are, therefore, decreasing. The pressure is equal to that of the condenser; that is to say, 0·03 atmosphere (29·1 inches), and the changeover valve is in its bottom position. At the point A, the manœuvring gear lever has been brought into the position for switching-in the turbine. After 20 seconds the hydraulic Vulcan coupling is so far filled that the turbine is driven by the piston engine, which is shown by the rising of the continuous line curve. In about a further 40 seconds, that is to say, when the point C is reached, the hydraulic Vulcan coupling is completely filled, and the turbine has reached the corresponding revolutions of the piston engine, in the present case about 1,950 r.p.m. Again, 20 seconds later, at the point D the piston of the changeover valve begins to lift, as shown by the rising of the dotted curve. This corresponds to what has been aimed at in the construction of the manœuvring device, namely, that the turbine shall not get steam before the hydraulic Vulcan coupling is completely filled with oil, for

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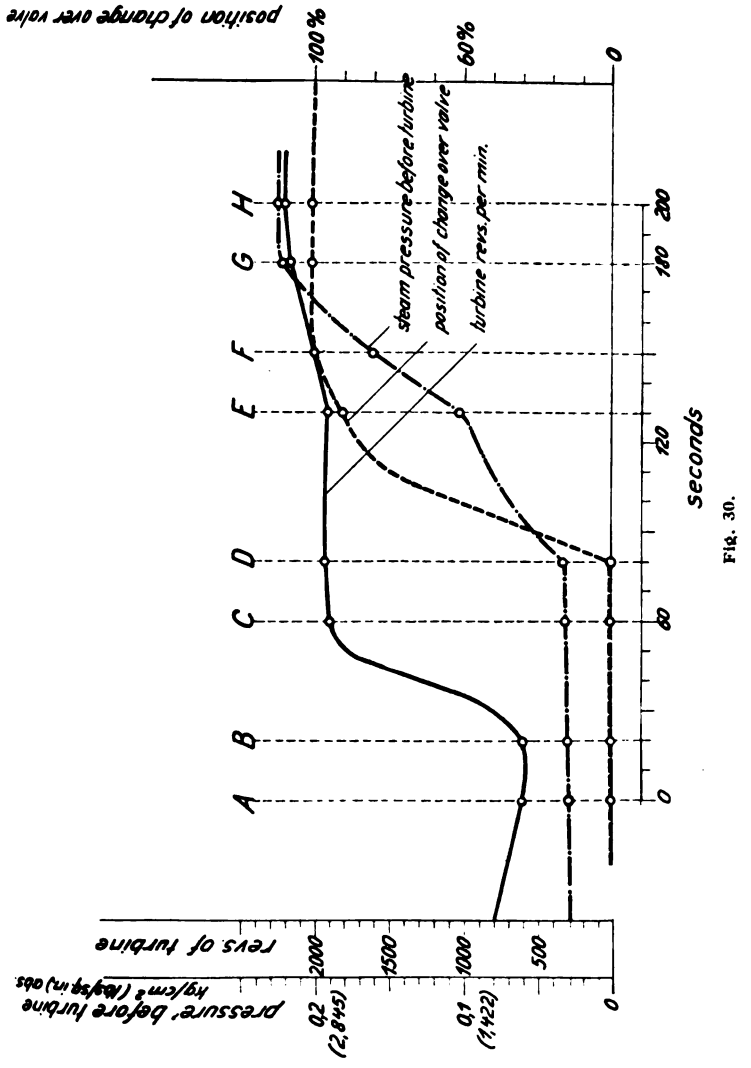

Fig. 30.

which reason the opening of the changeover valve to the turbine has been brought into automatic dependence on the filling of the hydraulic coupling. From the point D onwards, the change-

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over valve quickly opens towards the turbine, as seen from the quick rise of the dotted curve. At the same point D, as seen from the rise of the dotted and chain-dotted curves, the pressure of steam entering the turbine also starts to rise. At the point E, therefore, a further acceleration of the turbine revolutions takes place, so that the revolutions of the piston engine, which is now assisted by the exhaust turbine, are also increased. At the point F, as seen from the dotted curve, the changeover valve is completely open towards the turbine, while at the point G the pressure of the steam entering the turbine has attained its full value. At H the turbine has reached its normal revolutions.

As seen from Fig. 30, the total operation takes 200 seconds. It may be remarked that, in order to attain complete security, it is better to let the whole operation of switching-in the turbine take place somewhat slowly, to ensure the precise working of the automatic control gear. The time taken for switching-in the turbine is a matter of no consequence, since, as has already been mentioned, during manœuvres the turbine is out of action, and usually is only switched in when an unimpeded run is to be anticipated.

On the other hand, switching-out of the turbine can be carried out instantaneously in order that any sudden manœuvres may immediately be executed. The cutting-out can either be effected by a hand lever, which quickly brings the changeover valve to its bottom position (steam flowing to the condenser), or by the safety governor attached to the turbine, which also acts on the changeover valve, and can be worked by hand.

Improving the Condensing Plant of Existing Piston Engines.

Corresponding to the important part which, as we have seen, the height of the vacuum plays in the economy of the exhaust-steam turbine, it is necessary, when adding such a turbine to an existing piston engine, to improve the condensing plant. Regarding this point, the following may be remarked:—

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a. The cooling surface of the condenser is generally of sufficient size. Only if the quantity of steam to be condensed is more than 40 kg. per square m. per hour of cooling surface (8·2 lbs. per square ft. per hour), even by a large increase of the cooling-water quantity, it will not at normal sea-water temperature of 20° C. (68° F.) be able to attain a higher vacuum than 95 per cent. (28½ inches). Condensers which have more than 0·1 square m. (1·076 square ft.) of cooling surface per i.h.p. almost always suffice for attaining all vacua practically required.

b. Normally it is not necessary to change the construction of the condenser, with the exception of enlarging the exhaust inlet, which is generally never sufficient for the requirements of the exhaust turbine. This is most easily accomplished with condensers having sheet-steel shells. The inlet opening can in such cases easily be increased to any extent, and a new saddle fixed to the shell either by riveting or welding. In the case of a cast-iron condenser, either a new shell must be provided with enlarged exhaust inlet branch, or, after having enlarged the opening, a new saddle of sheet copper or brass fixed.

Exhaust inlet openings of 0·4 square m. (4·31 square ft.) per 1,000 i.h.p. of the total output of piston engine and exhaust turbine generally suffice for all purposes.

c. The capacity of the exhaust cooling-water pump is also generally too small. In many cases it is sufficient to replace the pump wheel, which generally is not very efficient, by a better one; in other cases it will, however, be necessary to provide a new cooling-water circulating pump. The quantity of cooling water required per kg. (2·205 lbs.) of steam consumption of the total output of the piston engine and exhaust turbine, at various sea-water temperatures for a given vacuum, is shown in the curves, Fig. 31.

d. It is essential to provide an efficient means of extracting the air from the condenser. It is, therefore, always necessary to fit a steam ejector, or so-called "vacuum augmenter." The suction pipe of the ejector is preferably placed where it is not

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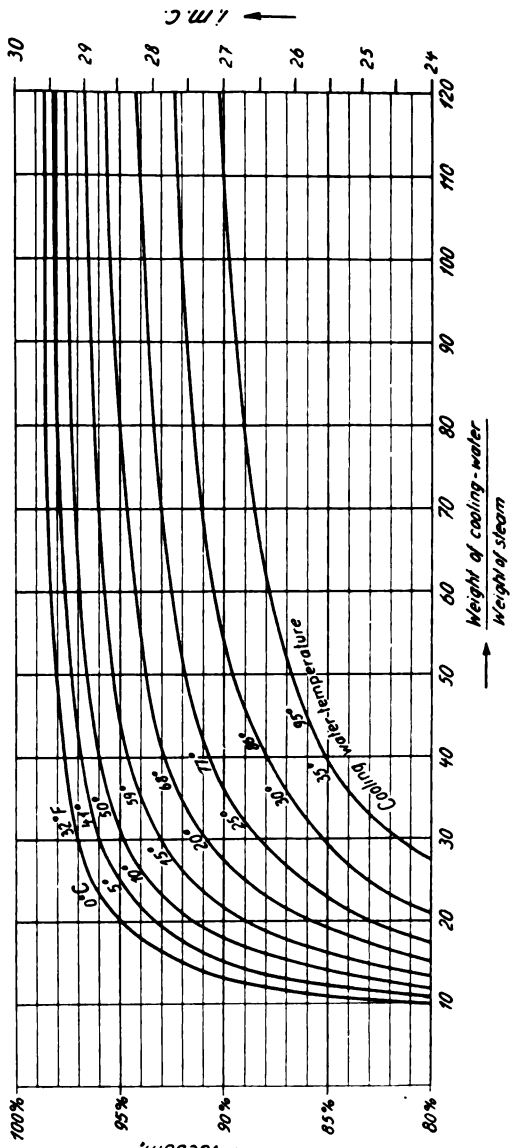

Fig. 31.

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affected by the direct flow of the steam, and where the temperature in the condenser is lowest. Preferably the ejector should be so arranged that it compresses the air from the condenser to from 85 to 90 per cent., and delivers this compressed air into the suction pipe of the air pump attached to the piston engine.

In order that the difference in pressure thus attained may not be destroyed by the connection between the suction pipe and

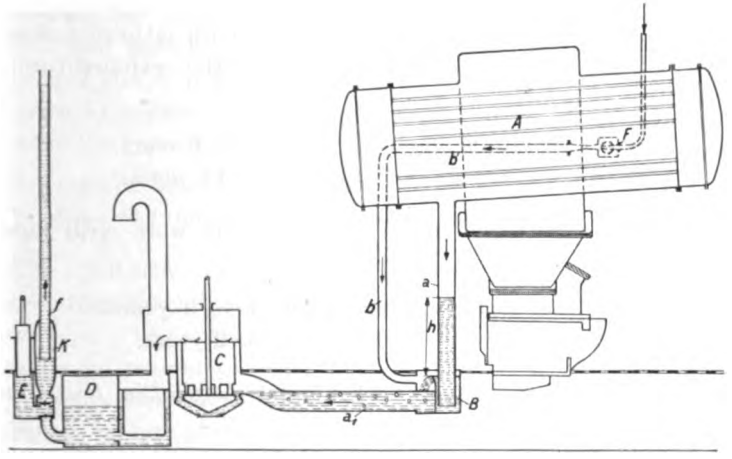

Fig. 32.

the condenser, a water seal is placed between these two parts, which water column is of sufficient height to equalise the differences in pressure.

The above-mentioned arrangement, which has been adopted for a large number of ships fitted with exhaust turbines, is shown in Fig. 32. F is the ejector with suction opening to the condenser, and B is the water seal. The latter is formed like a jet-condenser, in order that it may be used for condensing the steam of the ejector. This arrangement has the advantage that the heat contained in the ejector exhaust, heats the condensate up to the same temperature as before the addition of the exhaust turbine.

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The Commercial Advantages Derived From the Installation of an Exhaust Turbine.

Considering first *the conversion of existing piston-engine steam plants*, the shipowner must judge whether the gain resulting from the exhaust-turbine installation brings a sufficiently rapid amortisation of its cost. From the actual manufacturing and installation costs of a large number of cases, and from the savings in fuel actually attained, the following deductions have been made:—

In a plant of medium size which works with saturated steam, under normal conditions, the cost of the exhaust-turbine installation is written off—

a. With coal firing in about from 3 to 4 years.
b. With oil firing in about from $1\frac{1}{4}$ to $1\frac{3}{4}$ years.

With very economical plants which already work with superheated steam—

a. With coal firing in about from 4 to 5 years.
b. With oil firing in about from $1\frac{1}{2}$ to 2 years.

The above figures are based on normal installation costs, and not on exceptional cases.

The manufacturing and installation costs of the exhaust-turbine plants vary according to the current rates of wages, and are further dependent on the structural arrangement of the piston-engine plant to which the exhaust-turbine installation is to be added. The more favourable figures mentioned above apply to ships which trade more in cold than in warm waters, and, further, to relatively high outputs for which the manufacturing and installation costs are comparatively lower than for smaller plants, and finally to average prices of fuel. In ships which bunker for the whole journey at the place of departure, the amortisation is accelerated, as on account of the smaller quantity of fuel required for the journey more cargo can be taken.

If the shipowner does not desire a saving in fuel, but an

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increase of speed, the advantages are often very great; in fact, so great that the installation of an exhaust-turbine plant is an absolute necessity. This is the case when ships of one line are appreciably surpassed in speed by competitive ships, and are, therefore, unpopular with passengers or shippers. Here a gain in speed of one knot, which has often been attained by the installation of an exhaust turbine, can give back to the ship its former value. Even if the circumstances are not quite so favourable, it must be remembered that the increase of speed decreases the number of sea-days during which fuel is consumed and passengers have to be provided for. Further, the utility of the ship is greatly increased by the greater number of possible voyages per year.

As to the gain in speed, under normal conditions this will be—

In ships of from 11 to 13 knots, about from 0·8 to 0·9 knot.
In ships of from 14 to 16 knots, about from 0·9 to 1·2 knot.

The conditions are somewhat different with regard to the installation of combined piston-engine exhaust-turbine plants in new ships. The outputs for which such plants come into question lie in general between 1,000 and 6,000 i.h.p. per shaft. For powers below the first-named figure, combined piston-engine exhaust-turbine plants will often be considered to be too involved, whilst for powers above the last-named figure the general leaning is towards geared-turbine installations. In my opinion, however, engineers of many steamship lines will prefer the more robust piston engine, which, through the addition of an exhaust turbine, has also become highly economical, to the more sensitive turbine. A new ship with an exhaust-turbine installation hardly costs more than one with an ordinary piston engine of the same output, as on account of its greater economy the extra costs of the exhaust-turbine plant are set off by the decreased cost of the piston engine and boilers with their auxiliaries, etc. Therefore, in all cases where, within the above-mentioned power limits, steam propulsion comes into question, the combination of piston engine and exhaust turbine should seriously be considered.

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View Into the Future.

It is only a small step from the plants described in the foregoing, in which the piston engine drives the propeller shaft direct, whilst the exhaust turbine drives it through gearing, to a plant in which both units drive the propeller shaft by means of gearing.

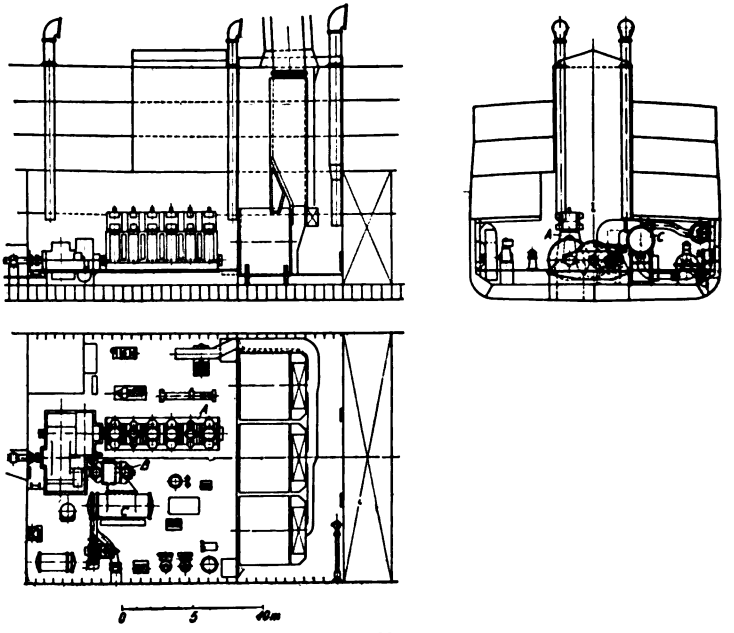

Fig. 33.

Fig. 33, which is taken from my paper read before the Schiffbautechnische Gesellschaft in 1925, shows such a plant for a freight-ship of 9,500 tons deadweight and 4,100 s.h.p. The boiler pressure is 16 atmospheres (227 lbs. per square inch absolute), the steam temperature 375° C. (707° F.), the revolutions of the piston engine 225, those of the exhaust turbine 2,500, and those of the propeller shaft 75 p.m. The piston engine A is a six-cylinder drop-valve engine with two H.P. and four L.P. cylinders. From the piston engine

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the steam flows to the exhaust turbine B with a pressure of about 1·5 atmosphere (21·4 lbs. per square inch absolute), and thence to the condenser. By means of a change-over valve for reversing, the steam from the piston engine is led to an astern turbine contained in the casing of the exhaust turbine. The piston engine is connected to the pinion of the main gear wheel by a hydraulic Vulcan coupling, whilst the exhaust turbine drives the main gear wheel through double-reduction gear without interposition of the hydraulic coupling.

The piston engine has an output of 70 per cent., and the exhaust turbine 30 per cent. of the combined output. The probable steam consumption of such a plant, together with that of the auxiliaries for driving it, is about 3·5 kg. (7·71 lbs.) per i.h.p. per hour, and the coal consumption 0·41 kg. (0·904 lb.) per i.h.p. per hour, based on the indicated output of a direct driving piston-engine of the same total power. Such plants could be manufactured very cheaply, if made in large numbers, as the quantity of material required is comparatively small and the fabrication simple.

There is no doubt that the present endeavour to introduce steam of high pressure and high superheat into marine engineering will find a commercial realisation, as experience has shown that all measures which serve to increase economy, even though often kept back through practical and other difficulties, are, nevertheless, finally adopted. Cylindrical boilers, however, cannot be used for generating steam of very high pressure, which requires water-tube boilers. If coal is to be burned, coal-dust firing must be considered.

Pure turbine-plants are not suitable for working with high steam-pressures, as in reaction turbines the clearance losses, and in impulse turbines, through the necessity of using partial admission, the windage losses are too large. The piston engine, especially of the high-speed type, is, according to all tests to date, well suited for working with highly-superheated high-pressure steam, as it is very reliable, and has a very high thermal efficiency, up to 90 per cent. of the adiabatic heat-drop being converted into indicated output.

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For the utilisation of high-pressure, high-superheat steam plants of this type are strongly recommended, as they combine high reliability with exceptionally low fuel-consumption. It is, therefore, to be expected that in the near future shipowners will evince great interest in installations of the types described.

Discussion.

Mr. JAMES RICHARDSON, B.Sc. (Member of Council): During the last few years we have had the honour of welcoming here a number of distinguished engineers from abroad, and in most cases the subject with which they dealt was the internal-combustion engine. To-night Dr. Bauer has dealt with the steam engine; in other words, he has met us more, if I may so describe it, on our own wicket.

The improvement in overall efficiency which results from the combination of a reciprocating steam-engine, exhausting into an L.P. turbine, is not in itself a novelty. The point, however, of the schemes for which Dr. Bauer is largely responsible is the combination of the reciprocating engine and exhaust turbine working on one propeller shaft, and, therefore, applicable to installations of quite moderate power. It will be realised that this development is made possible, *firstly*, by the perfection of the manufacture and cutting of mechanical reduction gearing, and *secondly*, by the interposition of that small element, the Vulcan hydraulic clutch. There is at least one engineer present to-night who has had experience of the economies resulting from that combination, and I hope he will be persuaded to give to this meeting the benefits of his actual experience at sea with such a system.

The torque diagrams, Fig. 29, show how the perfectly even torque of the steam turbine can be superimposed on the very irregular cyclical torque of the multiple-crank reciprocater, to such effect that the maximum torque is less, even at the considerably increased power of the combined system. There are other similar examples where a very small invention has

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been the reason for phenomenal success and great development, such as the pneumatic tyre, which made cycling possible and popular, and the well-known Michell thrust, which undoubtedly has contributed enormously to the rapid development of huge and powerful marine steam turbines. In a somewhat similar way, I think this Vulcan coupling makes Dr. Bauer's system possible and profitable. I was fortunate in being able to take a short voyage—it was an actual voyage, not a trial trip—on one of Dr. Bauer's converted steamships, the "Vigo," belonging to the Hamburg-Sudamerikanische Dampfschifffahrts-Gesellschaft. My keenest impression of the operation of this system was the extraordinary way in which the switching-in of the exhaust turbine, as graphically described by Dr. Bauer, did definitely sweeten up the running of the whole main-propelling plant, concurrently with a very substantial increase in propeller revolutions, giving very visible and very audible evidence of that sweetening up of the torque which Dr. Bauer's records have proved.

Dr. Bauer is modest, and I had some difficulty in getting from him to-day some figures to show the extent to which this system has been applied in his own country recently. I think I am right in saying that it was only proposed as recently as 1924, developed in 1925, the first order booked at the beginning of 1926, and the first ship put to sea in the autumn of 1926. To-day, that is, within considerably less than two years, there are 16 ships at sea, totalling 43,000 i.h.p., while for conversions and for new ships Dr. Bauer and his associated companies have on order 150,000 i.h.p., making a total of nearly 200,000 i.h.p., and that for a type of installation that, as will be appreciated, is not confined by any manner of means to relatively high-powered steamers. These figures are further testimony to the courage, the capacity, and the determination of our friend and guest of this evening, Dr. Bauer.

Mr. G. Fred Tweedy, O.B.E.: I am very glad to have an opportunity of personally congratulating Dr. Bauer on his most excellent paper, and upon the manner in which he has read

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Mr. G. Fred Tweedy, O.B.E.

it in what is to him a foreign language. Some years ago my firm built and engined two passenger vessels fitted with the combination system of reciprocating steam-engines and L.P. turbines, and from the results of these two vessels I can confirm the economy referred to by Dr. Bauer in his paper. Incidentally, I might mention that the changeover automatic valves, which cut out the turbines when going astern, were fitted in these vessels, and they worked entirely satisfactorily. The L.P. turbines were driven by independent shafts, the turbines being on the wing shafts. Undoubtedly the fitting of L.P. turbines on independent shafts means that the first cost of the installation is somewhat on the high side, and I think Dr. Bauer is to be congratulated on having adapted this scheme to a single line of shafting, which I feel will considerably reduce the first cost. It is of great interest and importance that this system can be fitted to existing vessels having reciprocating steam-engines, as there is undoubtedly a large number of such vessels which cannot possibly compete in these days, unless they are brought more into line with the more efficiently driven vessels. The Bauer-Wach system enables this to be done, as there will either be an increase in economy for the same speed or for the same fuel consumption, or a corresponding increase in speed.

Prof. A. L. MELLANBY, D.Sc. (Member): I should like to congratulate Dr. Bauer upon his very neat solution of a problem that has engaged the attention of engineers for many years. This question of utilising high vacuum has often been considered by engineers, but there has always been a feeling that, with the ordinary tramp steamer at least, high vacuum meant low temperature of condensate, and consequent probable reduction of overall efficiency. Some years ago the late Mr. D. B. Morison read a paper* in which this particular problem was brought forward. Mr. Morison claimed that the higher the vacuum the better should be the efficiency, and he based this

* Trans. North East Coast Inst. of Engineers and Shipbuilders, vol. xxvii, p. 31.

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Prof. A. L. Mellanby, D.Sc.

claim upon the fact that there is always sufficient waste heat available to raise the feed-water temperature to a sufficiently high value. There were some people who disputed this statement, and I think representatives from this district made the most serious opposition to Mr. Morison's proposal. As mentioned by Dr. Bauer, there is always an appreciable pressure drop between cylinder and condenser, but one of Mr. Morison's points was that, if greater attention were given to the design of the L.P. cylinder exhaust ports, the increased condenser vacuum would be reflected by an appreciable gain of work in the cylinder. With Dr. Bauer's scheme of combined reciprocating engine and turbine, the pressure drop difficulty vanishes, and also, as he so clearly shows, the increased work obtained from the further expansion adds appreciably to the work obtained from the steam. It will, however, be of interest to have Dr. Bauer's opinion upon this question of feed-water temperature, and to learn whether the much cooler condensate that will be delivered by the air pump can be heated economically and simply to a reasonable degree.

There is one point about which I find myself in a little opposition to Dr. Bauer, and that is the so-called deleterious effect of the temperature range in the L.P. cylinder to which he refers on page 260. Now, it is a good many years since we had very lively discussions in this hall on cylinder condensation, and I think by now most people really know that the old ideas of cylinder condensation were much exaggerated, and that it is not nearly so serious a matter as the older text-books state. Experiments made on multiple-expansion engines with different amounts of vacuum always show a steady increase of efficiency as the back pressure is lowered, and readings of cylinder-wall temperatures show no great change through a fair range of test conditions. It occurs to me to ask—and I make the suggestion with great diffidence—whether it would not be better to use a compound instead of a triple-expansion engine. The compound engine might have two L.P. cylinders, so that the usual three cranks could be still employed, the expansion would not be carried so far, and more work could be obtained

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from the turbine. It would entail a smaller engine, and all the cylinders could probably be made of about the same size. The turbine, of course, would have a higher initial pressure, and a great many air leakage difficulties would be eliminated.

I suppose everyone will recognise that these developments, as well as the developments that were mentioned at the North East Coast Institution of Engineers and Shipbuilders the other week, where reference was made to a reciprocating marine-engine using steam at 500 lbs. pressure and 750 degrees F., are the inevitable reaction that everyone expected as soon as the Diesel engine was introduced. It is particularly interesting to note the success of the efforts that have been already made to bring the fuel costs of the steam-driven more nearly into line with those of the Diesel-driven ship, and Dr. Bauer is to be congratulated upon the part he has taken in bringing about this increased economy.

Mr. JOHN JOHNSON: It seems to me that the natural starting point in the discussion is to make a comparison between Dr. Bauer's proposals and the somewhat analogous system we are accustomed to, namely, the three-shaft arrangement, employing reciprocaters on the wing shafts exhausting into an L.P. turbine actuating the centre shaft. The company I am connected with have two such ships, the machinery of which was converted to use superheated steam about three years ago. Twelve months later, propellers of modern design were fitted. The total reduction in fuel consumption was of the order of 450 tons per passage, or 900 tons per voyage. Now, I mention these figures so that it may be realised that the fuel rates which I quote later are based on careful measurement, and are not in any way devised for exhibition purposes. In these vessels the fuel consumption per horse-power (i.h.p. and s.h.p.) for propulsion is a little less than 1 lb. of coal, which, converted to a basis of s.h.p., may be taken as 1·07 lb., and this in association with hand-fired Scotch boilers where the average efficiency probably does not exceed 72 per cent. With a boiler efficiency of 80 per cent., such as would be realised with

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Mr. John Johnson.

improved methods of burning coal, the foregoing consumption rate would be a little less than 1 lb. of coal per s.h.p. per hour. The corresponding rate for oil may be readily assessed. It will be seen, therefore, that Dr. Bauer has not exaggerated in the claims he makes for increased thermal efficiency.

Any person interested is naturally disposed to inquire what advantage the Vulcan clutch and double-reduction gearing possesses over the three-shaft arrangement. In the vessels I have mentioned we had occasion closely to examine the efficiency of the three propellers, and found that the wing units gave 65 per cent. and the centre unit 56 per cent., yielding a mean efficiency of 62 per cent.; that is to say, a loss of 3 per cent. at that end compared with the twin-screw arrangement. Dr. Bauer, however, states that the transmission loss through gearing and clutches amounts to 3 per cent. This, of course, would only apply to one-third of the power transmitted.

This subject falls naturally into two divisions, namely, the adoption of the system for new tonnage, and its application to existing tonnage. In the case of new tonnage, where high efficiencies are predicted, higher pressures are inevitable, and, I think, necessarily water-tube boilers. Reciprocating engines, employing a considerable amount of oil for internal lubrication, would not be admissible even with the most careful filtration. Moreover, the overall thermal and mechanical efficiency of a straight turbine installation is such that the combination of reciprocating and turbine machinery would scarcely be entertained. As regards existing tonnage, it is difficult to express an opinion unless the actual weight and space, capital cost, maintenance expenses, etc., are closely examined. Owners will not embark on an appreciable capital expenditure unless they see a prospect of an early return. The proposals, therefore, would not be acceptable in vessels of appreciable age. The question arises whether the addition of double-reduction gearing, hydraulic clutches, forced-lubrication pumps, filters, coolers, etc., with the corresponding structural alterations, really compensates for the fuel economy. A further point to consider is whether existing

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Mr. John Johnson.
reciprocating engines could be driven at appreciably greater revolutions without detriment.

Mr. C. R. H. Bonn (Associate Member): Dr. Bauer has dealt very comprehensively with this most interesting development, which, whatever the possibilities of its application to new ships, promises to be largely adopted in steamships which have to compete with motorships. To a large coal-producing country like ours, this development is of particular interest, inasmuch as it will enable the steam engine to compete more successfully with the Diesel engine, and thus enlarge the market for British coal, which is contracting at present owing to the increasing use of oil fuel.

In following the paper, I am tempted once again to reflect on the great complications involved whenever an attempt is made to increase the efficiency of heat engines, and to wonder if there is not, after all, something fundamentally wrong with the way in which the problem of converting the energy of chemical combination into mechanical energy, is tackled. It seems as if there were room for some revolutionary design here.

It is evident that the fluid clutch plays a very important part in this arrangement, and I think it might be well worthy of some further consideration in Dr. Bauer's reply to the discussion on his paper. From the diagrams, the clutch appears to be slightly different in construction from the Vulcan clutch described in a previous paper submitted to this Institution, and to resemble somewhat the Föttinger gear, from which I believe it is derived. It is well known that the action of the clutch depends upon the liquid shear, and that this shear has something to do with the vortices set up between the blades owing to their relative motion; but it appears that the vortex velocities must be very high in order to account for the small slip. Some explanation of what takes place inside the clutch while in action would, I am sure, be highly appreciated, and would complete Dr. Bauer's excellent description of this interesting apparatus.

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Mr. R. J. Walker, C.B.E.

Mr. R. J. WALKER, C.B.E. (Member): Dr. Bauer covers a great deal of ground traversed by Sir Charles Parsons and others some 20 years ago. At that time the primary object of the combination of reciprocating engines with L.P. turbines was to widen the field of the application of turbines to ordinary cargo vessels and vessels of the intermediate freight and passenger type, where the speed and power fell below that at which an all-turbine direct drive was advocated. The difficulty of reconciling the opposing factors of the high-speed turbine with a low-speed propeller presented certain limitations to an all-turbine drive for the class of vessel I have mentioned.

In 1908 I was associated with Sir Charles Parsons in a paper read before the Institution of Naval Architects, wherein the various applications of the combination of reciprocating engines with L.P. turbines, with resultant economies, were dealt with. A further paper* on the combination system, as fitted in the s.s. "Otaki," was read by Engineer-Commander Wisnom before this Institution in 1909. It must be remembered that at that time the gearing of the turbine to the propeller had not become an accomplished fact, with the exception of that fitted in a small launch of 10 h.p.

The statement in Dr. Bauer's paper that at higher pressures the steam turbine has no advantages over the piston engine, is true with direct-coupled turbines in slow-speed vessels. This disadvantage was removed by the introduction of gearing in the "Vespasian" in the year 1909, thereby enabling marine turbines to be designed for higher speeds of rotation. The use of a low-pressure or exhaust turbine geared to the shaft of reciprocating engines is referred to in one of Sir Charles Parsons' earlier patents, and while it was considered, it was not prosecuted, because it was realised to be better to gear the whole of the turbines to the propeller shaft and retain all the advantages of the turbine drive, which are well known.

As regards steam consumption for the installation of 3,590 equivalent i.h.p., referred to by Dr. Bauer, the figure of 8·67 lbs.

* Trans. of the Institution, vol. lii, p. 279.

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Mr. R. J. Walker, C.B.E.
per i.h.p. becomes 9·7 lbs. taking s.h.p. In the "Cairnross," fitted with a modern installation of all-geared turbines and of somewhat less horse-power than the example given in the paper, the consumption was 9 lbs. per s.h.p. under about the same conditions of boiler pressure and superheat.

The loss with the hydraulic coupling for neutralising the uneven turning of the piston engine is given as 3 per cent. Other means can be adopted to introduce flexibility, such as the fitting of a spring coupling with effective means of damping. Examples of such combined elastic coupling and frictional damper have been fully described in the discussions on papers read before the Institution of Naval Architects and the North East Coast Institution of Engineers and Shipbuilders. By its means the 3 per cent. loss attributable to the hydraulic coupling would be saved. In earlier vessels where the combination of reciprocating engine and turbine was fitted, there was no difficulty presented in regard to the shutting-off of the exhaust turbine during manœuvring, suitable change valves being fitted whereby the exhaust turbines were automatically cut off when the vessel was going astern.

I am afraid I must disagree with Dr. Bauer's conclusions as to the future, when he states that pure turbine plants are not suitable for working with high steam-pressures. In the case of an existing vessel fitted with reciprocating engines, the addition of an exhaust turbine will undoubtedly give economical results and an increase in power, but in the case of a new vessel, from the evidence and data at present available, my opinion is that turbines are eminently suitable for higher pressures, and that maximum economy of steam plants will be obtained in a complete turbine installation; moreover, with turbine machinery, there are very great advantages in the entire absence of reciprocating parts, no valve gear, no moving parts in contact, reduced weight of machinery, etc.

Mr. W. H. Howden (Member): Dr. Bauer mentions that a combination of reciprocating engine and exhaust turbine was evolved some considerable time ago, but was not developed

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owing to the engineers concerned not realising the possibility of this idea. My knowledge of this problem was gained on the land side of electrical generation in public power stations and private installations. At the time of the introduction of the L.P. turbine, it was anticipated that a considerable amount of extra energy could be developed at practically the same steam consumption by attaching L.P. turbines to existing reciprocating engines. It was fully realised what advantages could be obtained from the increased efficiency of the L.P. cylinder of the existing piston engine, owing to the decreased pressure and temperature drop across the cylinder, with the consequent reduction of condensation losses, and, at the same time, the added economy which could be obtained from the turbine at the lower pressures, due to its capability of accommodating the large volumes of steam consequent on high vacuum expansion. In installations of reciprocating engines from 750 b.h.p. upwards, it was found in general practice that the increased output was about 30 per cent. greater than the output of the engine alone, with practically the same steam consumption under both conditions.

In 1911, I was connected with the installation of an exhaust-steam turbine of 6,750 b.h.p. at 1,500 r.p.m., with a steam pressure of from 1 to 1½ lb. above atmospheric pressure. The steam was drawn from three reciprocating engines of 2,250 b.h.p. each. The engineer concerned considered that the results showed the advisability of extending this principle to other reciprocating engines in the power station. The reason for the non-development of this principle was the advent of the 3,000 r.p.m. turbo-alternator, the cost and consumption of which showed a better return for the capital expended than the composite idea. In the case of marine work, the development of the comparatively high-speed turbine with first single- and then double-reduction gearing, of which the "Vespasian" was an early example, had the same effect on the composite principle, and this interesting phase of development was more or less abandoned until revived by Dr. Bauer, who combined with it his ingenious use of the hydraulic coupling. The advantages

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Mr. W. H. Howden.
of the combination of the exhaust turbine and gearing with the existing reciprocating engine on board ship would appear, from Dr. Bauer's figures, to show a return on the capital expenditure.

If possible, I should like Dr. Bauer to say more about the use of both high-pressure and high-temperature steam in specially-designed reciprocating engines, to be used in conjunction with exhaust turbines possibly allied to electrical propulsion; such an arrangement would obviate the use of the gearing and the hydraulic coupling. If this type of machinery is to compete with the Diesel engine, it would seem necessary to take advantage of steam of a high total temperature.

Prof. W. KERR, Ph.D., A.R.T.C. (Associate Member): It is very surprising to examine, in the light of marine engineering history, the elements of the system which Dr. Bauer so clearly describes. It is to be observed that the system involves combination propelling machinery of reciprocating engine and turbine, double-reduction gearing, and what is, in its essentials, a Föttinger transformer. Each, separately, has been well tried, but to some extent discarded. Yet they are now found grouped together in an attractive scheme, which has been well worked out, and for which a sound claim is made. This claim is well supported by figures, clearly developed and presented in a highly convincing fashion. Fig. 5 appears to show that the excellence of the combination is, to a considerable extent, due to the poorness of the full range L.P. cylinder in ordinary triple-expansion working. It is doubtful whether this rather low efficiency is generally characteristic of such cylinders, and hence the benefits demonstrated in this case may be unduly high. Increase of the cylinder back-pressure leads ostensibly to a decided improvement in cylinder efficiency, but this is still below what a turbine can be made to give over this range. Hence it might be possible to make out a case for a wider expansion range in the turbine and the adoption of a simplified compound-engine arrangement. Even with such a limitation of engine range, it would be possible to reach the percentage

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astern power usual in marine work without calling upon the exhaust turbine in manœuvring operations.

Apart from all minor points, however, it is clear that the essential feature of the system lies in the connection between the turbine and the shaft, and in this considerable ingenuity has been displayed. The necessity for flexibility has been well appreciated and excellently worked out. But this flexibility has a double aspect. It is necessary, and advantageous, in view of the inherent differences in the drive characteristics of the engine and turbine; but disadvantageous in that it tends to introduce the possibility of criticals into the system. It might be difficult in all cases to ensure that these were not searched, within the speed range, by propeller effects or by harmonics of the torque. The hydraulic coupling is probably admirable as a damping or absorbing influence, but the elastic system between the coupling and the shaft would have to be designed under the somewhat restrictive conditions of sufficient flexibility for torque variation, and sufficient rigidity to keep natural frequencies beyond the range of trouble.

In view of what has happened recently in regard to double-reduction gearing and its use in connection with turbine installations, it is particularly surprising to find such a method proposed in a combination scheme, and it must be supposed that the justification lies in the use of the hydraulic coupling. At the end of the paper Dr. Bauer says that pure turbine plants are not suitable for high pressures because of clearance and windage losses, but this is hardly the case. With the separate casing arrangements common in marine work, and with the freedom in choice of rotational speed which is permitted by the use of double-reduction gearing, it is quite possible to keep the high-pressure end losses down. It must, therefore, be submitted that, on the basis of any double-geared arrangement that could make an engine and turbine combination a success, an equally good, or superior, case could be made out for an all-turbine drive with a similar scheme of transmission gear. I must confess to holding the opinion that,

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Prof. W. Kerr, Ph.D., A.R.T.C.
while this new development of a combination engine and turbine system possesses distinctive merits as a means whereby existing engine arrangements may be improved, it has not the same merits as a scheme for new installations, and certainly not for new installations of medium powers.

Mr. A. CAMPBELL (Member of Council): Since the Diesel engine has become a serious competitor of the steam engine for marine propulsion, designers and makers of steam engines have schemed more than ever to make their particular type more efficient and economical. The recent developments of the exhaust-steam turbine, as described by Dr. Bauer, are a decided advance in that scheme of economy, and should give the steam reciprocating engine a fresh lease of life. The exhaust-steam turbine is certainly not a recent idea, but the method of application in the Bauer-Wach system—the exhaust turbine working in conjunction with reduction gears and the Vulcan coupling—has many novel features, and, with an increase in power of from 20 to 25 per cent. without any increase of coal consumption, should prove an attractive proposition to many shipowners, particularly as this system can be embodied in most of the older vessels.

When I first heard of this method of increasing the horse-power by so much, it seemed only reasonable to assume that the diameter of shafting would require to be increased in proportion, but I can now see that this additional power involves, in most cases, no alteration of the shafts, as the constant torque of the turbine helps to smooth out the unevenness of the torque diagram of the reciprocating engine, and should not exceed the maximum torque as developed by the reciprocating engine. The power of the turbine must vary in proportion to the back pressure of the L.P. cylinder. I have no doubt, however, that the back pressure in the I.P. and L.P. cylinders can be so adjusted as to keep the powers of the cylinders fairly equal.

In the case of an existing triple-expansion engine with the condenser fairly high, say in line with the guides, if an exhaust

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Mr. A. Campbell.

turbine were fitted at or near the centre line of shafting, that is, below the condenser, I should imagine there might be some trouble by condensed steam lying in the bottom part of the turbine casing. It would be interesting if Dr. Bauer would enlarge on this problem.

Mr. JOHN S. BROWN, M.B.E. (Member): One of the features which distinguish reciprocating engines used for land purposes from those in the marine service is, that the marine engine has no fly-wheel. In the land engine the purpose of the fly-wheel is to reduce the cyclical fluctuations in speed to within prescribed limits, depending on the service requirements; and where a small fly-wheel is accepted the speed fluctuations are quite considerable. It follows from this that the marine engine also works with a considerable speed fluctuation, but experience has shown that this is not detrimental to the propulsive efficiency. However, Dr. Bauer proposes to couple a turbine to the main-engine drive; and a turbine is essentially a constant-speed machine of high rotary inertia, so that there is a distinct clashing between the characteristics of the two units. Further, as the transmission also includes a reduction gear, it is necessary to accept that under no conditions will the torque taken from the turbine fall below zero in value, as this could only result in a reversal of the loading on the gear teeth. This position is responsible for the special features of the long elastic shafts and the hydraulic coupling on the turbine drive. While this arrangement will allow the two units to be coupled together without introducing completely unacceptable conditions at the gear, it remains necessary to notice that the gear loading varies considerably, and the size of the gears must be proportionally increased. Even so, it would appear that the eventual wear of the gears may lead to variations in the pitch of the teeth around the main gear wheel. This matter has doubtless received serious consideration, but it would be useful to have definite figures from Dr. Bauer, showing the load variation involved in a representative design, and also a figure for the "slip" accepted in the clutch;

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Mr. John S. Brown, M.B.E.
for, while an increased slip will be helpful in one direction, it will lead to heating effects on the fluid charge which forms a member of the clutch.

Attention may usefully be drawn to the importance of the chart of the world, Fig. 10, showing isothermals of the sea-water temperature. This temperature controls the available vacuum, and it is not sufficiently realised that a ship engaged on a definite trade-route in the tropics may be completely excluded from using the upper range of vacuums, and under which the turbine gains such advantages over the reciprocating engine. Thus there have been cases where turbine ships were bladed for a vacuum of 28 inches, and were then compelled to operate over long periods at about 25 inches vacuum. Under such conditions, the final stages in the turbine would be of no assistance, and in the present proposals corresponding limitations would again operate. Thus the commercial merits of the plant cannot be fully established by a trial trip in our own latitude, except for the special case of a vessel trading, say, on the North Atlantic. However, these remarks are only intended for general information, as the fact that Dr. Bauer has given us the chart is evidence that he appreciates the practical aspect of the position.

Mr. James Andrews (Member): It must be particularly interesting to marine engineers on the Clyde to be told in the introduction to Dr. Bauer's paper that "At the higher pressures, however, the steam turbine has no advantages over the piston engine," because we have recently seen a set of turbine machinery put into one of our river steamers to work at the abnormally high pressure of 565 lbs. per square inch absolute. Without having gone into the question, it was a feeling akin to that which prompted me to say in the discussion of Mr. Mollison's paper, read before the Institution last year, that "it would be interesting to see what progress in working pressure or economy could be made with the steam engine under similar enterprising auspices."

The combination of piston engines and exhaust-steam

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Mr. James Andrews.

turbines is not new in this country. About 25 years ago several vessels were so fitted, but I am not aware that any one of them was particularly successful when the extra cost and complication were taken into consideration; at all events, little was heard about them, and they seem to have been given up by shipowners. They were mostly on separate shafts driving separate propellers, but many marine engineers and shipowners would consider that to be an advantage, because it would be easier to deal with in the event of a breakdown. Then why have those exhaust-turbine combinations not been repeated in the last 20 years? In a paper on "Progress in Economy of Turbine Machinery" read before the North East Coast Institution of Engineers and Shipbuilders last session by the Hon. Sir Charles A. Parsons, the only figure given for a combination set of piston engine and exhaust turbine is for the "Otaki" working at 215 lbs. absolute pressure, which consumed 13·7 lbs. of steam per s.h.p. for all purposes. The corresponding figure for the "Cap Norte" seems to be 9·7 lbs. per s.h.p., or 29 per cent. better than the Parsons Co. can produce.

Here let me ask why the i.h.p. of the exhaust turbine is found in the paper by dividing the s.h.p. by the fraction of mechanical efficiency of the piston engine. This seems to me to give a purely hypothetical power which does not exist in fact. If steam consumption is to be compared with power, then I think that it should be actual power, either s.h.p. or, if i.h.p. is preferred, then the s.h.p. of the turbine should be divided by the fraction of mechanical efficiency of the turbine to obtain the power put into it, as in the case of the piston engine.

Now, why should the combination plant on the "Cap Norte" be so much more economical than the "Otaki"? Of course, sometimes piston engines give as great a difference in economy, but the "Cap Norte" was fitted with a triple-expansion engine having a small cylinder ratio from H.P. to L.P. cylinders in relation to the superheated-steam pressure of 216 lbs. per square inch absolute. This engine was an unusually economical one, using 11·08 lbs. of steam per i.h.p., which would be

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Mr. James Andrews.

equivalent to about 1¼ lb. of coal per i.h.p. with a moderately economical boiler.

Most shipowners would have been content to let well alone with such an economical plant as that, but I think that Dr. Bauer has been fortunate in meeting such enterprising owners, and they have been rewarded by a further 22 per cent. saving on their already low coal consumption, which would bring it down to about 1 lb. of coal per i.h.p. This is an excellent result to be obtained with superheated steam at 216 lbs. absolute pressure, compared with that of the turbine steamer "King George V" with 565 lbs. absolute pressure, or the triple-expansion engines of the "Borneo" with 515 lbs. absolute pressure. At the same time, it must not be forgotten that an equally excellent result was obtained with piston engines alone on the "Inchkeith" and her sister ship, built on the north-east coast in 1899, which was supplied with saturated steam at 275 lbs. absolute pressure, and was reported to consume 1 lb. of coal per i.h.p. for all purposes. This, however, is not the best result obtainable with the exhaust-turbine combination, because under the heading of "Commercial Advantages" it would appear that a greater saving is obtainable by adding an exhaust turbine to a less economical piston engine using saturated steam; or, as it is put in the paper, the cost of the exhaust turbine is written off in a shorter period.

I think that is a claim which requires some qualification, because a great deal will depend upon the cylinder ratios of the piston engine in relation to horse-power, initial pressure, and the back pressure of the L.P. cylinder. With the cylinder ratios of triple-expansion engines in common use at the present time, I think that it will be necessary, in most cases, to fit a liner in the L.P. cylinder when an exhaust turbine is to be combined with a piston engine. This would not only tend to equalise the powers, loads, and range of temperature in the cylinders, but it would reduce the steam and exhaust velocities through the L.P. ports and valves due to speeding up the revolutions of the engines.

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Mr. James Andrews.

Comparing the results obtained from the "Cap Norte" with those of the "Otaki," it seems obvious that the former is one of the exceptionally economical plants that are not often repeated, and we need not expect to equal it by the combination of an exhaust turbine with a less economical piston engine using saturated steam.

Of course, a considerable part of the increased power in the combined engine and exhaust turbine is due to the improved vacuum. Now, I think that a simpler method of obtaining an improved vacuum could be adopted than the vacuum augmenter shown in Fig. 32. In that case the air is forced through the water lock in the air-pump suction into the air pump, and the air pump discharges it. If, instead of that system, an air-suction pipe be connected to the condenser at F, and led to a non-return valve immediately below the head valves on the Edwards air pump, then the unrestricted air is drawn directly into the air-pump barrel during the down stroke of the bucket before the water gets into the pump, and is discharged with the water on the up stroke. This method has the advantage of being simple, cheap, and effective.

Dr. BAUER: First of all, I wish to express my thanks to Mr. Richardson for opening the discussion, and for his recognition of the merits of the innovation with which my paper dealt. I know that he is thoroughly conversant with the details of the exhaust-turbine system, and I appreciate the statement of his impressions resulting from the voyage which he made on the s.s. "Vigo."

I would stress the consideration that, since the exhaust turbine works on the same shaft as the reciprocating engine, this arrangement is particularly suitable for small- and medium-powered ships for which the pure turbine drive does not generally come into question, and that, furthermore, the hydraulic Vulcan coupling is the factor of prime importance which has enabled the powers from the turbine and reciprocating engine to be combined to drive on one propeller shaft. The data given by Mr. Richardson of the extent to which this

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system has been and is being adopted, are, of course, an effective corollary to my advocacy.

Mr. Tweedy relates the interesting experience of his firm with two large passenger ships, each having a reciprocating engine on the centre shaft and an exhaust turbine on each wing shaft, and I am glad to note that his experience with these vessels has been very satisfactory. There is no doubt that these two ships, with exhaust turbines, built by Messrs. Swan, Hunter & Wigham Richardson, Ltd., as well as the large ships with exhaust turbines on separate shafts, built in other British yards between 1910 and 1913, have given extremely good results in every way, especially in regard to economy, even although the comparatively slow-running turbines, necessitated by the direct coupling to the propeller, could not attain anything like the same degree of economy possible with the Bauer-Wach system, where the exhaust turbine runs at a speed of revolution compatible with high turbine efficiency. The favourable results attained with these ships contributed to the development of the scheme to enable smaller- and medium-sized vessels to utilise the advantages of an exhaust turbine by a suitable means of combination.

Prof. Mellanby raises the point of the lowering of the temperature of the condensate, resulting from the extra vacuum required by the exhaust turbine, having a detrimental effect on the overall efficiency. Closer investigation shows that this cooling of the feed is only a negligible factor in comparison with the large gain resulting from the increased expansion ratio with the exhaust turbine in circuit. The extra quantity of heat required for raising the temperature of the feed from that corresponding to the normal vacuum of a reciprocating-engine installation, is a very small fraction of the gain attained through the large expansion ratio of the steam. For this reason, with exhaust-turbine plants, the highest possible vacuum, regardless of the lowering of the temperature of the feed, must always be the aim.

Our measurements do not altogether agree with Prof. Mellanby's contentions regarding condensation on the cylinder

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walls of reciprocating engines, and in all our experience we have found that the output of the L.P. cylinder is very little decreased when the exhaust turbine is switched into the circuit, in spite of the fact that when the exhaust turbine is out of action the back pressure on the L.P. cylinder is considerably lower. We have no other explanation for this phenomenon, other than that with the exhaust turbine in the circuit the efficiency of the L.P. cylinder is substantially increased, which can only be accounted for by decreased condensation.

I agree with Prof. Mellanby that there is no theoretical consideration against utilising a compound engine in lieu of a triple-expansion engine with the exhaust turbine, and at the commencement of this development I personally advocated repeatedly such a design, but was unsuccessful, since the superintendents of shipping companies preferred to retain the normal reciprocating engine with H.P., I.P., and L.P. cylinders, to which an exhaust turbine was simply added. To some extent this is natural, as those pioneers who first shouldered the responsibility of the introduction of this novel form of propulsion wished the assurance that, should the exhaust turbine be out of action, the complete reciprocating engine would be at all times available. I wish especially to thank Prof. Mellanby for his recognition of our efforts to increase the economy of marine steam plants.

Mr. Johnson, from his wide experience, has compared the gains with the exhaust-turbine system with those from triple-screw installations, in which the middle propeller shaft is directly driven by an exhaust turbine fed from the reciprocating engines on both of the wing shafts, and arrives at the same conclusion regarding steam economy. Mr. Johnson raises the question as to whether the weight and expense of the exhaust-turbine system under discussion justifies its adoption. I would refer, in this connection, to my remarks on page 298, where this point has been fully dealt with, and can only reply that actual experience in a large number of varying types of ships has answered this question in an entirely favourable way. Of

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course, the savings with the Bauer-Wach exhaust-turbine system will be greatest where oil firing is adopted, in which case the savings will write off the first cost well within two years. Older ships which only have a few remaining years of useful life do not, as a rule, form suitable subjects for conversion.

The answer to Mr. Johnson's query regarding the possibility of running existing reciprocating-engines at higher speeds when the exhaust turbine is in circuit, is categorically in the affirmative, assuming that, through the addition of the exhaust turbine, a power increase of 30 per cent. is attained, which means only an increase of 10 per cent. in the speed of revolution, since the increase in revolutions only corresponds to approximately the third root of the power increase. With this increased speed of revolution, the variation in turning-moment is decreased from plus or minus approximately 60 per cent. to plus or minus approximately 25 per cent., with a corresponding increase in cyclic regularity, as explained on page 289. The records I possess of this improvement in the running of a reciprocating engine are confirmed by the experience of those who have seen these plants in operation at sea, and this point was specifically dealt with by Mr. Richardson.

Mr. Bonn refers to the importance of this innovation to coal-producing countries, such as Great Britain, since this system brings the steamship into more direct competition with its motor-driven rival. A comparison of the fuel costs of a coal-fired steamer with an exhaust-turbine plant, and the oil-fuel costs of a Diesel ship, shows that only in special cases where the motorship can bunker oil at low prices can it compete with the steamship. Any serious student of the subject of improving the economy of steam plant comes to the same conclusion as Mr. Bonn, that it seems at first sight unsatisfactory to attempt this improvement by apparently complicated arrangements attached to an unsatisfactory prime mover, and that efforts might be better directed to discovering a new and more economical way of converting the energy of the fuel into work. Innumerable workers have endeavoured to dis-

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cover some new method, but, quite apart from the fact that the second law of thermodynamics imposes rather restricted limitations, we cannot await the discovery of some new process, and must direct our energies, so far as is possible, to small improvements in economy of the conversion of heat to work.

Hydraulic couplings interposed between the driving and driven members of a mechanism have been in use for a very long time. The Vulcan couplings, which are used with exhaust-turbine plants, are based on the construction originated by Prof. Föttinger, in which each half-coupling is formed like a turbine wheel, consisting of a semi-spherical cup provided with radial vanes. The oil flows from the driving half to the driven half and *vice versa* in a series of eddying currents. In operation, the motion of the fluid in the coupling is similar to that of smoke rings. The power which maintains each eddying ring is the superior centrifugal force resulting from the slightly higher revolutions of the driving half. The slip between the driving and the driven halves is directly proportional to the power which can be transmitted by the coupling, *i.e.*, if the slip in the coupling is increased, a larger power at the same revolutions can be transmitted. For a given number of revolutions and a given output, in order to obtain zero slip, the couplings require to be of infinitely great diameter. The speed with which oil circulates from one half of the coupling to the other, that is to say, the velocity of each eddying ring, is exceedingly small, and decreases with the decrease of slip. For practical purposes, in all couplings these velocities are of the order of a few metres per second, so that the question of wear of the internal surfaces of the couplings does not arise.

In reply to Mr. Walker, I may emphasise the remarks in the introduction to my paper regarding my keen appreciation of the fact that Sir Charles Parsons and other engineers recognised the value of exhaust-steam turbines. The system I have described is merely one of new ways and means of utilising a known principle.

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With regard to the interposition of a hydraulic clutch, I have repeatedly considered the fitting of other types of coupling, but I have an antipathy to elastic couplings utilising springs, etc., which may cause most inconvenient vibrations. In addition, and of primary importance, the hydraulic clutch serves the purpose of switching the turbine in and out rapidly and safely, which cannot be achieved by any other form of coupling. These considerations are, in my opinion, of much greater moment than the relatively very small loss of turbine power of from 2·5 to 3 per cent. Whether, in a special case, for instance, 20 per cent. instead of 19·4 per cent. of fuel is saved by the fitting of an exhaust-steam turbine, cannot be said to be of first importance.

I maintain my standpoint that high-pressure turbines of small or medium power, taking steam at extraordinarily high pressure and high superheat, are not entirely satisfactory. The experimental steamer "King George V," fitted with H.P. turbines, has one common H.P. turbine which delivers steam to turbines geared to both shafts, in order to mitigate these difficulties. This method is not generally a desirable solution, and it does not eliminate the disadvantages of extremely short blades and relatively large clearances.

Some of Mr. Howden's criticisms are dealt with in my reply to Mr. Walker. On the question of high-pressure reciprocating engines, the use of which I advocate strongly in association with the exhaust-steam turbine, I take this opportunity of explaining the subject in further detail. Reciprocating engines, working, for instance, with 375° C. (707° F.) initial temperature and a steam pressure of from 40 to 60 atmospheres (570 to 850 lbs. per square inch), should, in my opinion, preferably be of relatively high speeds of revolution and geared to the propeller. The dimensions of the cylinders thus become less, and it is possible also to distribute the power over a greater number of cylinders, which is always advantageous where high steam-pressure and temperature stresses are involved. Furthermore, these engines should have a larger number of cranks than normal in order to secure as

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perfect a balance as possible, and should, in short, be very similar in design to the standard enclosed forced-lubricated Diesel engine. For high initial steam-pressures, triple-expansion might be recommended where three of the six cranks are driven by L.P. cylinders, three by I.P. cylinders, and several H.P. cylinders arranged on the top in tandem fashion.

In replying to Prof. Kerr, I may say that the decrease in the temperature range of the reciprocating steam-engine is readily understood from the thermodynamical point of view, and the reduced temperature drop can, of course, be dealt with by a compound engine. At first I designed plants of this type, and for conversions proposed to remove the L.P. cylinder altogether. In doing so, there was the additional advantage that space was made available for the exhaust-steam turbine and plant. This scheme was not carried out because the compound engine has great disadvantages relatively to the three-cylinder engine, as regards balance and facility of manœuvring, and because the bigger turbine necessary, with attendant larger gear, substantially increases the price of an exhaust-steam plant.

With respect to torsional vibrations, the steps taken by Dr. Wach and myself, in order to provide compensation between the even turning-moment of the turbine and the uneven characteristics of the reciprocating engine, eliminate the possibility of critical vibrations arising. Of course, it is desirable in every special case to make the necessary simple calculations to discover where a critical speed might lie, when it is only a small matter to eliminate such a possibility by designing the gear correctly. Our experience with a large number of ships now shows definitely that there has never been even the slightest indication of any torsional vibrations, nor any undue stresses in the teeth which might be caused by vibrations of this type. Proposals preferring the high-speed reciprocating engine using steam of high pressure and superheat, to turbines, for plants of small and medium power, have been referred to in my reply to Mr. Howden.

I thank Mr. Campbell for his appreciation of the system,

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Dr. Gustav Bauer.

and can assure him that very careful consideration was given to the question of turbine drains. Where the turbine is arranged low down, *i.e.*, underneath the condenser, a special drain pump is usually fitted. This pump under the floor plates is driven from the circulating-pump engine by means of a downward-working eccentric or connecting rod. A sufficient drop can be arranged in this way between the bottom of the turbine casing and the drain pump.

If I correctly understand Mr. Brown, he fears that, owing to the uneven torque of the reciprocating-engine shaft, considerably higher stresses may come on the teeth of the gearing than are consequent on the transferring of the turbine power to an evenly-turning main wheel. It is difficult to ascertain exactly the amount of these higher stresses in the teeth of the gearing. With the usual design of exhaust-steam turbine, they are, in my opinion, very small, and probably amount at most to a few per cent. The fluctuations in the linear velocity of the main gear wheel are only relatively small on account of its weight, although the torque of the piston engine shows considerable irregularity; therefore, the teeth of the large wheel will only accelerate and decelerate those of the pinion to a negligible amount. It is certain, however, that so far no wear whatever has appeared on the teeth of the wheels or pinions of the exhaust-steam turbine plants, from which it may be concluded that the dimensioning of the gears has been such as to carry the load imposed.

Further, in my opinion, the extent of the slip in the hydraulic coupling is of some considerable importance in assisting to negative any tendency to increased teeth loads. The figure of from 2½ to 3 per cent. for the slip of the coupling which is usually chosen, means that a smaller slip would increase the coupling diameter, and consequently, raise the price for the exhaust-steam turbine plant, while, on the other hand, an increase in slip would diminish the possible increase of fuel economy, which is obtainable by means of the exhaust-steam turbine. Therefore, from 2½ to 3 per cent. slip is probably the best compromise.

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Dr. Gustav Bauer.

As regards the influence of sea-water temperature on the economy of the exhaust-steam turbine plant, the map of the sea-water isothermals shows that there are certain short voyages where it is difficult to obtain high vacuum, and consequently, also economical working of the exhaust-steam turbine plant. During all long voyages, as mentioned in the paper, the sea-water temperatures are equalised on the whole voyage, so that a favourable mean temperature can generally be relied upon.

Mr. Andrews asks why in recent years exhaust-steam turbine plants have not been built for larger ships. Firstly, before the introduction of the system developed by Dr. Wach and myself, exhaust-steam turbine plants required a separate shaft for the turbine. The arrangement of three shafts can, of course, only be considered for very high outputs, where the pure turbine drive is the most suitable. There was the further disadvantage that the turbine drove directly on the shaft, so that not only was it heavy and expensive, but its revolutions were much too low for economical steam consumption in the turbine, and too high for satisfactory propeller efficiency.

I consider it quite probable that a return will be made to reciprocating engines and exhaust-steam turbines for twin-screw ships up to total horse-powers of the order of 10,000, as even for such high outputs the exhaust-steam turbine system has considerable advantages. Even with a separate shaft for the exhaust-steam turbine, such outputs must be considered as the higher limit for which the triple-screw arrangement is suitable. The calculation of the i.h.p. of the exhaust-steam turbine by dividing the effective output by the mechanical efficiency of the reciprocating engine gives, of course, only a calculated figure which corresponds to the normal method of stating total output. Plants which, before conversion, show similar steam consumption figures to the "Cap Norte" have frequently been built within recent years; they owe their efficiency to the use of superheated steam as well as to the correct dimensioning of the steam ports, limiting the clearance volume, etc. It is understood that the total steam consump-

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tion of a combination consisting of an exhaust-steam turbine with a very uneconomical reciprocating-engine is greater than if the combination were based upon a steam engine of high economy. In this connection, it should be emphasised that the connection of an exhaust-steam turbine to an uneconomical reciprocating-engine will give a particularly high relative gain, so that an engine of low economy combined with an exhaust-steam turbine is not much inferior to a combination arrangement with a reciprocating engine of high economy. The difference is not nearly so great as between reciprocating engines alone, the one of high and the other of low economy.

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FACTORS OF SAFETY AND QUALITY OF MATERIAL.

By W. H. Riddlesworth, M.Sc., M.Eng.,
Member of Council.

20th December, 1927.

Introduction.

By way of introduction, I submit the following quotations from four well-known authorities:—

Reuleaux.

"The factor of safety is the ratio between the breaking load and the actual load. . . . Care must be taken never to permit a material to be strained in use to its theoretical resistance; although, indeed, there are some materials, such as wrought iron, which have been strained slightly beyond the limit of elasticity, without reducing the breaking load, or causing any apparent injury.

"The determination of the breaking load, and consequently the use of the modulus of rupture, is limited to those cases in which the actual breaking of the structure must be considered; but for the calculations of working machinery the modulus of resistance, or limit of elasticity, is of primary importance."

Rankine.

"A factor of safety, when not otherwise specified, means the ratio in which the breaking load exceeds the working load. . . . The breaking load of a body is the load required to produce fracture in some specified way."

Perry.

". . . a factor of safety, which is the ultimate strength divided by the working strength. . . . Here the factor of

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safety is four. We do not mean, or rather, we ought not to mean, that we might put four times the working load upon the structure before breaking. . . . The factor of safety allows for contingencies . . . risk of defects . . . deterioration with time . . . inaccuracy in our theory or our estimated loads . . . unforeseen causes of shock or of fatigue . . ."

ST. CATHERINE OF SIENNA.

"My son, avoid confusion of mind."

In the course of my work I have often made use of a factor of safety, and have generally taken it to mean the ratio of breaking to working stress, but in many cases, *e.g.*, long struts, a designer does not have to provide against breaking but against buckling, and I question if we can just substitute "buckling" for "breaking" in the above definition and carry on with a factor of safety of a certain value.

I have passed as satisfactory, structures for which the additional deflections due to working or test loads have been entirely recoverable, but for which nothing was known about the actual stresses, and those due to the weight of the structure itself were obviously not small.

I have designed structures with factors of safety of normal value, and on the other hand have designed successful structures in which the maximum possible stress, save under grossly improper and highly improbable conditions (which would at once double the stresses), was equal to about one-half the tensile breaking stress.

The difficulty of reconciling the definitions of the authorities and the effects of practice form quite a good excuse for the confusion of mind against which the fourteenth century Saint warns her disciple, and which I own I suffer from. I trust that the discussion of some of my thoughts and tentative decisions about the matter, will tend towards the removal of some of the uncertainties which beset all those who are endeavouring to design and build structures in which unnecessary material is eliminated, and in which each part contributes its due share

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to the general success; structures which, like the Deacon's one-horse shay, are built to break up all at once, not one part first.

The introduction of special steels having an elastic limit considerably higher than that of ordinary mild steel, affords a reason for a re-examination of two questions in connection with structural design.

What do we mean by factor of safety? What are the most desirable strength properties in the materials used?

It is not the purpose of this paper to attempt to fix a value for the factor of safety, but rather to indicate some of the considerations which should govern its magnitude, to relate it to the appropriate strength property of the material, and to afford some guidance towards a proper choice of the materials available.

A factor of safety, called by the cynic, with some degree of truth, a factor of ignorance, is, it will be admitted, the ratio of the stress at which failure would take place to the working stress. But what is failure? It is not necessarily actual fracture, for many a forging and many a casting would be condemned were there any permanent distortion after it had been tested to twice the working load; many a bridge would be counted a failure did it deflect more than a specified fraction of its span under working load; many a machine tool would be an utter failure were there any measurable distortion under working conditions; while many a bulkhead would fail were the deflection to exceed some unknown but comparatively small amount sufficient to produce leakage.

There are at least two criteria of failure, namely, actual rupture and excessive distortion. Actual rupture is a gross thing, and there can be but little doubt about its occurrence or otherwise. Excessive distortion is a matter of definition, and what may be excessive distortion in one case may be negligible in another. In many cases excessive distortion may be taken to be one from which the structure does not completely recover on removal of the load, whilst in other cases an excessive distortion is one which exceeds some function of dimensions of the structure.

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It is surely true to say that the forging which just passes the test *(ante)* has a factor of safety of two, that the bridge which just shows the specified deflection under the working load, together with the bulkhead which has been stiffened up and supported until it will just hold in water, have each a factor of safety equal to unity.

With ordinary structures of ordinary materials, none of these examples would be near failure by actual rupture, and all too often we confuse ourselves and others by stating, *e.g.*, that the forging has a factor of safety of about five, just because it happens to be stressed to about two-fifths of the ultimate stress when under test to twice the working load, or that the bridge has a factor of safety of about five because the induced stress when the permitted deflection is obtained is about one-fifth of the ultimate.

Having seen that failure requires some definition, we may turn to consider that failure may take place under normal working loads, under abnormal loads, or because of lack of uniformity or of premature decay in the material used.

It may be said that a factor of safety proper provides against the first contingency, and a factor of ignorance against the others, but unfortunately in many cases the stresses due to working conditions can not be determined with precision, and again we have to call in the aid of the factor of ignorance.

Quite a small factor of safety provides ample security against failure under working loads when the stresses can be predicted with accuracy, but some sort of evaluation of probabilities has to be made in an endeavour to provide against uncertain working stresses, abnormal loads, decay, etc.

The practice of using a larger factor of safety for gear liable to abnormal loads (such as hoisting gear) than for mere structural supports, and of using a larger factor of safety for timber structures than for steel, show how this evaluation has proceeded.

In past experience factors of safety have been fixed with regard to ultimate strength alone, but with the advent of new

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materials it behoves us to examine the foundations on which that experience has been built, and it may very well be that suitable factors of safety for such materials will only be acquired as the result of much experience and many trials and errors. One fully reported failure would do more to establish a basis than scores of structures which do not fail.

An attempt is made in the following table to indicate the peculiar strength quality or property of the material upon which failure depends, for each elementary structural part and for each mode of failure:—

TABLE I.

Type of Part.	Mode of Failure.		
	Fracture.	Distortion.	
		Permanent Set Limit.	Dimensional Limit.
Tension member - - -	U	Y	E
Compression member, short -	U	Y	E
„ „ long -	U & E	Y & E	E
Shear member - - - -	U	Y	N
Beam - - - - - -	U	Y	E

Where U = Ultimate Stress.
Y = Elastic Limit Stress.
E and N are Moduli of Elasticity.

If the criterion of failure be rupture, ultimate strength is the important property; if it be distortion, then modulus of elasticity and elastic limit stress come in order of importance.

In long compression members and in beams where distribution of material is of importance, it should be noted that a specified distortion limit is not sufficient for determination of the required scantlings; a limit must also be set upon the induced stresses, which may be referred to either the ultimate or the elastic limit stress.

The material strength qualities of a number of steels now

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on the market are tabulated below, and certain deductions drawn therefrom:—

TABLE II.

	Mild Steel. Ship.	High Tensile Steel. Admiralty.	High Elastic Limit Steel.	
			Martin.	Service.
U. Tons per square inch -	30	35	32·5	37·3
Y. Tons per square inch -	8	14	16·5	24·6
E. Lbs. per square inch -	30×10^6	30×10^6	$1{\cdot}08\times 30\times10^6$	$30{\cdot}3\times10^6$

Ultimate and elastic limit stresses vary widely, but the modulus of elasticity is practically the same for all; variations of about $\pm$ four per cent. occur in samples from the same melt.

In cases where there is merely a dimensional limit to the deflection, one quality of material is as good as any other; where there is a permanent set limit, the qualities range themselves in order of elastic limit stress, whilst for simple rupture they range in order of ultimate stress.

For many structures it is not known exactly what form failure really takes. Consider the case of the structure of a ship. Are we to anticipate failure by actual fracture or by excessive distortion? Probably the latter, for most of the fractures heard of are merely local affairs due generally to discontinuities. It appears probable that the particular distortion to be guarded against has a dimensional limit, so that material with a high value of E is desirable, together with an elastic limit high enough to avoid permanent set when the permissible distortion has been reached.

Past experience has been based upon a factor of safety on the ultimate strength, as if the failure to be guarded against were actual fracture, and the practice of allowing higher calculated stresses in larger ships indicates, *inter alia*, that the method of stress calculation is not completely satisfactory; a dimensional correction appears to be called for.

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Any rational consideration of the question of using high elastic limit, high tensile, or other steel in ship construction involves the solution of the problems of the form of failure to be anticipated, and of the factor of ignorance to be applied to cover the unknown errors of the method of stress or deflection calculation now in use.

Discussion.

Mr. J. Lockwood Taylor, M.Sc.: Mr. Riddlesworth's paper falls into the class of what might be called provocative papers, rather than controversial, since there is not much in it with which to disagree, although there is plenty of matter for discussion, both in the paper itself and in the whole subject suggested by the title.

When Mr. Riddlesworth says that, unfortunately, in many cases the stresses due to working conditions cannot be determined with precision, I take it that he means they cannot be determined in advance, by calculation, because there is, of course, the possibility of stress measurement by various types of instrument, of which I think sufficient advantage is not as a rule taken. Regarding the factor of safety as a factor of ignorance, which it undoubtedly is to a very large extent, it is in this question of actual measurement of strains that the whole solution of the problem lies, if calculations are to be brought into line with actual facts, for any but the simplest type of structure. Until experiments of this nature have been more fully adopted, it must surely be admitted that the "ignorance" is of a wilful nature, and the "safety" not thereby increased.

He speaks of the evaluation of the "probabilities," *i.e.*, probable conditions of loading to be encountered, although with regard to many types of structure the word "possibilities" might perhaps rather have been expected, as, for instance, where imminent danger to human life would be involved in failure of the structure. With regard to ships, however, although there have been many observations of weather condi-

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Mr. J. Lockwood Taylor, M.Sc.,
tions, and a much smaller number of observations of actual stresses, he would be a bold man who would attempt to lay down definitely what are the worst weather conditions which can ever, under any circumstances, be met with at sea, and to interpret these conditions in terms of actual loading of the structure; thus it is only what is reasonably likely to be encountered which can be allowed for in design work.

In referring to the high calculated longitudinal structural stresses in large vessels, Mr. Riddlesworth evidently has in mind that these values are largely fictitious, and while this is an opinion very frequently expressed, I venture to say that, in the present state of knowledge of ship stresses, it is hardly possible to lay it down as a definite fact. Thus, it is known that certain very large vessels have had structural trouble of a more or less serious nature such as is practically unknown in small ships, and there are certain reasons why higher actual stresses may, or even must be permitted in large vessels, so that to this extent, at any rate, it is not imperative to question the validity of the assumptions of the standard strength calculation. Speaking from personal observation of stresses at sea,* although without wishing to generalise from a limited experience, it is the case that higher observed stresses have been found in the larger vessels. Thus, in a vessel of 530 feet, the gunwale stress exceeded 10 tons per square inch, and there is at least a suggestion that the figure of eight tons given in the paper as the elastic limit of mild steel (a figure which, incidentally, has come into prominence in connection with the advocacy of special steels) rests on a definition of elasticity rather too strict for practical application. The stress mentioned was compressive, the tensile stress not greatly exceeding eight tons. It is not, of course, by every wave that this stress is imposed, nor every voyage on which such storms are encountered, but the conditions were not really exceptional in any way, the officers' description being simply "whole gale, dangerous following sea."

Returning to the question of the factors which may be said

* Trans. Inst. of Naval Architects, vol. lxviii (1926), p. 259.

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to differentiate the allowable stresses in large and small ships respectively, these are at least three in number:—(1) The greater relative importance of corrosion in the smaller ship; (2) the greater liability to buckling of the small ship's thinner plating, with the usual frame-spacing, *i.e.*, the frame spacing does not decrease in proportion to the thickness of plating; and (3) the economic factor, which is never absent, but certainly predominates in relative importance in the case of the ship, as compared with other structures. To take a simple instance, reduction of depth/length ratio has such a prejudicial effect on the moment of resistance, and so small an effect on the bending-moment (the bending-moment due to waves alone is unaltered) that it simply is not feasible to adopt the same standard of longitudinal strength for the shallow ship, whereas if it were an engineering problem pure and simple, and the economic factor were absent, this would presumably be done. In ships, the weight factor (which is essentially economic) is, I suggest, so all-important as to prohibit, for instance, the adoption in the larger vessels of scantlings sufficiently heavy to reduce their stresses to normal limits, and from this point of view the limitation of absolute size, for deadweight carriers, is a very real one, and also possibly for liners, unless one is prepared to specify a maximum "standard" wave.

A plate structure, such as a ship, in which failure locally may not necessarily result in the adjacent parts being dangerously overstressed, must be distinguished from one in which the failure of a single member may lead to collapse of the whole, although any such occurrence would necessitate very careful handling of the ship. There is also the question of non-homogeneity, but the give-and-take allowed by riveted joints, functioning as they do largely by friction, may be an actual advantage in permitting redistribution of the stresses, as in the case of "the ship that found herself."

As regards factors of safety in transverse length, Dr. Bruhn has mentioned some measurements in the course of which he found higher transverse than longitudinal stresses, under the same weather conditions, and that has also been my experience,

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Mr. J. Lockwood Taylor, M.Sc.

and is in general agreement with the results of calculation, if the frame stresses are calculated for the same wave height (amidships) as for the standard hogging condition. The homogeneity of the frame itself may be an advantage, and probably a slight permanent set would not be serious, although it would result in loss of displacement and, consequently, of deadweight.

Mr. Riddlesworth, however, seems to favour the view that it is this question of distortion which is of greater importance than the stress itself, but can this apply, for instance, to longitudinal straining, apart from the consideration of local buckling tendencies? These tendencies must, of course, be investigated with the help of the ordinary strut theory, and with regard to "long" struts in general (for instance, the ordinary ship's derrick) the effect of live load appears to demand special consideration, this being one of the contingencies allowed for by the factor of safety, if based on statical strength calculations. The more suddenly the load is applied, the greater the inertia resistance of the strut against side-bending, a necessary preliminary to failure. The strut may not deflect sufficiently while the dynamic increase of load is acting, for failure to take place, so that while for a tension member the effective load is double the nominal, this is not the case for the member in compression, provided the load is sufficiently "live," *i.e.*, is removed sufficiently quickly. For a beam under live load, while part of the energy is for the time being kinetic, ultimately, when the beam reaches its maximum deflection, it is all strain energy, and this is the case for the strut also, with the difference that the total amount of work done by the load is not a linear function of the deflection during the time the load is acting, but a quadratic, and, therefore, of the second order of smallness as compared with the deflection itself.

To conclude, the general aim must be to abolish, or at least greatly reduce, a factor of safety which is largely one of "ignorance"; the general conclusion from the paper is that each type of structure, if not each individual structure, must

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be considered on its merits, but the need for further experiment may perhaps be reiterated, with a view to decreasing the ignorance and increasing the safety of all types of structure.

Mr. A. P. Cole, R.C.N.C. (Member): In his interesting paper Mr. Riddlesworth invites discussion on two very contentious questions, namely, "What do we mean by factor of safety?" and "What is failure?" These problems are not peculiar to the introduction of high elastic limit steel, and I personally do not see why any modification in the quality of material used should alter the views of anyone as to either factor of safety or failure. The essential qualities of elasticity, yield point, and ultimate strength remain, whatever type of steel is used, and it is only a question of the values to be given to each of these quantities that is affected by the type of material used.

With regard to the first of Mr. Riddlesworth's questions—"What do we mean by factor of safety?"—I do not think, so far as shipbuilding problems are concerned, that a complete or satisfactory answer has been made in the paper. Factor of safety is defined as the ratio of the stress at which failure occurs, to the working stress. Mr. Riddlesworth admits that the term "failure" requires further definition, and, indeed, deals with it in the latter part of his paper. But does he know what is the working stress in any part of the structure of the ship? To obtain the working stress, the conditions of loading, the mechanics of the structure, and the mechanics of the material itself must be known. With regard to the loading, it is not possible, in our present state of knowledge, to specify exactly what forces come on a ship in a sea-way, or what are the boundary conditions in a bulkhead, to quote only two of the many problems occurring. With regard to the mechanics of the structure, it must be admitted that in a ship we are dealing with a type of construction which has absolutely no counterpart in any other form of engineering, namely, the adoption, as the principal elements, of flat, thin steel plates which are riveted together to form the completed structure.

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Mr. A. P. Cole, R.C.N.C.

The properties of this type of structure cannot be accounted for by the usually accepted theories based on our knowledge of the strength of materials. As to the mechanics of the material itself, there is no doubt that certain elements of the ship's structure would be subjected to stresses beyond the yield point if they were constrained to retain their original shape, but owing to deformation, the loading is reduced, and the stress correspondingly diminished. The usual theories, however, are based on the parts retaining their original shape, and behaving throughout the whole range of stresses as if the material followed Hooke's law.

In each of these three cases, therefore, it is necessary to make certain assumptions which may, or may not, be near the truth, but which will enable us, with our present knowledge, to obtain a figure which, for convenience, may be called the stress in the material. But one would hesitate before saying that the figure so obtained is the actual or working stress; in fact, it is only a number which may be used, in similar cases and with similar conditions, for the comparison of similar structures. If such is the case, how can we talk with any degree of certitude of "factor of safety"? To a ship designer, the term is absolutely meaningless, and should be abolished from the dictionary of shipbuilding. As illustrative of the absurdity, consider the stress in a bulkhead stiffener when subjected to water pressure. In a certain case the fibre stress varied from 15 to 65 tons per square inch, according to the width of plating taken as acting in conjunction with the profile, the latter figure representing the condition with no associated plating. There is absolutely no reason, when considered from a comparative standpoint, why the 65 tons per square inch should not be taken as the 15 tons per square inch, but what would be the factor of safety in the former case?

The major part of Mr. Riddlesworth's paper is devoted to a discussion of "failure," and he makes certain proposals for defining failure. These proposals must be examined with care, as they hardly seem complete enough to cover the cases that

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may arise. The most important of the problems that arise in ship design are those in connection with permanent distortion or set, as those which come under dimensional limit are easily dealt with by suitable distribution of material, and those which fail under fracture are of very rare occurrence, and in any case would be dealt with under permanent set or deformation. Mr. Riddlesworth proposes the elastic limit (or, as would be the case in practice, the yield point) as the peculiar strength property upon which this type of failure depends. This does not appear, however, to go far enough, as there are various degrees of permanent distortion or set which can be accepted, under certain conditions, without danger to the ship. Provided, generally, that the permanent deformation is such that any subsequent load to which the material may be subjected will not result in a stress approaching the ultimate breaking stress, and also that the permanent deformation of the material does not affect the safety of the ship as a whole, then no objection can be raised to this permanent deformation. For example, a bulkhead under test pressure will often have stresses set up in certain parts of the structure which are beyond the yield point, and when the load is removed a certain amount of permanent set will remain. The probabilities are that the bulkhead will not again receive such a load except in an extreme case of damage, in which case the deflection will be increased, but provided the original permanent set is not excessive, the watertightness of the bulkhead is not impaired. It becomes, therefore, a question of experience to decide what permanent deformation can be allowed, and, therefore, what stress can be allowed in the material. Beyond the fact that this stress exceeds the yield point, it can hardly be said to bear any direct relation to the yield point.

The introduction of the modulus of elasticity together with the yield point in the permanent set limit column in Table I seems illogical, as it presupposes that the material is elastic beyond the yield point. A similar remark applies to the occurrence of E under the fracture column, and this line should be modified. A proposed modification is already sug-

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Mr. A. P. Cole, R.C.N.C.
gested by Mr. Riddlesworth himself in the last paragraph of page 333.

I would also suggest that Mr. Riddlesworth should modify the figures given in Table II so that they may be made consistent one with the other, observing that he appears to have quoted either the yield point or the limit of proportionality indiscriminately in the table. It should also be noted that the high tensile steel, Admiralty quality, does not represent the grade of steel now used in Admiralty work.

As indicated in my previous remarks, I am in full agreement with Mr. Riddlesworth, so far as ship structures are concerned, that failure should be anticipated by excessive distortion rather than actual fracture, but I am afraid it is too much to hope that one fully reported failure will ever be published—it is against human nature to do so. I am not, however, in agreement with the last paragraph of his paper, wherein he states that the rational consideration of the use of high elastic limit steel involves the solution of the problems of the form of failure to be anticipated, as these problems are fundamental whatever the type of material used, and Mr. Riddlesworth rather appears to have put the cart before the horse. In conclusion, may I congratulate Mr. Riddlesworth on his extremely interesting and ingenious paper, and also on his courage in tackling two such thorny and contentious questions.

Mr. J. L. Adam (Member of Council): Mr. Riddlesworth has given us a paper on a very interesting subject, but, in so far as it refers to ship structures, it is a subject of which we know so little that any discussion must be largely academic. In any case, it does not seem to me that the title really indicates the contents of a paper which deals rather with possible differences in scantlings due to the use of materials having different physical properties. In trying to define failure in a ship structure, he gives as criteria fracture of, or undue distortion in, the structure, but such fracture or distortion need not necessarily mean absolute failure if the ship can still fulfil the specified conditions.

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Mr. J. L. Adam.

This leads to the consideration of undue distortion. If undue or excessive distortion is defined as occurring when material is stressed beyond the so-called limit of proportionality, then there seems to be no reason why that should, in all cases, entail failure. We have reason to believe that ships occasionally do meet circumstances in which the material in the structure is stressed beyond the limit of proportionality, but as these occasions probably occur at wide intervals, the time element comes into our reckoning, and the material has the chance of recovering its physical properties in greater or less degree.

I question the statement that, in past experience, factors of safety have been fixed with regard to ultimate strength alone, because I do not think it applies to modern practice in designing ship structures. Great care is taken to ensure, as far as is practicable, that there will not be such deflections as will result in disturbance of connections and consequent development of defects in the structure. Deflection or distortion, as Mr. Riddlesworth indicates, is probably the most difficult feature, and one of the chief factors to be kept in mind when designing ship structures, but although the modulus of elasticity of the material used is a measure, as between one metal and another, of the possible deflection or distortion, I would ask Mr. Riddlesworth if it is quite true to say that one steel is as good as another, even if the limits of distortion are strictly confined to such a point as will keep the stress below the limit of proportionality. Are we to assume that one steel is as good as another in resisting repeated distortion, or bending, or constant reversals of stresses?

I think Mr. Riddlesworth must have something more in his mind than is indicated by his statement at the end of his paper regarding the comparative stresses in large and small ships. I am sure that it is within his knowledge that there is a very great difference in the calculated stresses on the gross section of a ship and on the nett section; that is to say, the section after allowances for corrosion, etc., have been made. As the allowance for corrosion, as between ship and ship,

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Mr. J. L. Adam.
is more or less constant, it will be obvious that the disparity of the calculated stresses on the gross section of large and small ships will largely disappear when the comparison is made on the nett section.

Dr R. M. Brown (Member): The question of the factor of safety, its basis, and the value to be assigned to it, has long been a vexed question. The basis of the factor must be decided upon before the question of its magnitude can be discussed, and Mr. Riddlesworth wisely confines his discussion to the former problem, or rather, to a very partial aspect of the problem; his remarks do not fully state the difficulties of the question.

He defines factor of safety as the ratio of the stress at which failure would take place, to the working stress, and he states that part of his purpose is to relate the factor of safety to the appropriate strength property of the material. He indicates some of the difficulties which arise when attempting to define when failure occurs, but he says very little about the difficulties which arise in defining the "appropriate strength" of the material. When failure cannot be definitely defined, the stress at which failure occurs is necessarily indefinite, and when the appropriate strength cannot be stated, the problem is obviously full of uncertainties. Mr. Riddlesworth simplifies his problem by confining himself, more or less, to statical load conditions. Loads may be roughly grouped into three classes:—

1. Loads gradually applied and maintained steady.
2. Pulsating loads which vary more or less rhythmically, which may change sign, but which fluctuate without producing impact stresses.
3. Loads, suddenly applied, which produce shock, or impact stresses.

These three classes of load may shade, one into the other, the essential difference lying mainly in the time element—the time taken to apply the load, and the duration of the applica-

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tion of full load. When the time elements are sufficiently dissimilar, the three load conditions give entirely different appropriate strengths—creep limit or ultimate strength, endurance range, and impact value respectively; the values assigned to these appropriate strengths vary also with the type of machine used in the test. The temperature of the material under test, the natural frequency of the structure, and the relationship between the period of vibration and the frequency of the load cycle, are factors which may, very profoundly, affect the value of the external load, and thereby cause failure of the structure or machine part under investigation.

Mr. Riddlesworth restricts his discourse to the simplest possible case, and if the resulting discussion promotes a clearer understanding of the elements which affect the value of the factor of safety under statical conditions, an advance will have been made which will assist in solving the major problem.

Failure due to rupture is something quite definite; failure due to strain or distortion is, in many cases, quite indefinite, and may even be a matter of opinion. There might be considerable distortion in some member of a roof truss without thereby endangering the stability or the safety of the roof, and, unless someone thought that it looked dangerous, the truss might continue to give satisfactory service almost indefinitely. In other cases, a strain of a small fraction of an inch might lead to failure, either by leakage or by fracture, if clearances were restricted. The question of permissible distortions must be considered for each part separately, when its purpose and its configuration, with respect to adjoining parts, are known, and the total amount of strain permissible is frequently one of the most important factors in determining a suitable working stress, and, therefore, also a suitable factor of safety.

The modulus of elasticity of a metal, such as steel, may be regarded as, for all practical purposes, invarable, and it will play no part in fixing the factor of safety unless "chord moduli" are considered. Mr. Riddlesworth discusses the elastic limit stress in its relationship to the factor of safety.

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Dr. R. M. Brown.

It cannot be too definitely emphasised that this, so-called, elastic limit is not a fundamental property of a material, and it is of no practical importance to the engineer. The value obtained for the stress at the limit of proportionality depends very largely on the sensitiveness of the measuring instrument. When a sufficiently delicate extensometer is used, it appears to be very doubtful if stress is proportional to strain, even at low stresses. In the light of present-day knowledge, it is reasonably safe to modify the statement of Hooke's law, thus:—Unit strain is some function of the applied unit stress, but it is not a straight-line function. The engineer is not concerned with whether the stress-strain graph is mathematically straight or not—he seldom investigates the relationship between stress and strain—but he requires to know that the departure from straight-line conditions is not sufficient to invalidate or to complicate his calculations unnecessarily; he requires that the modulus shall be high, so that he can use the minimum cross-section, and also avoid excessive distortion, at stresses which give a reasonable margin of safety over his calculated working stresses.

For statical loads, the "proof stress" offers many advantages as a basis of the factor of safety, although it is a purely arbitrary stress, and is in no sense a fundamental property of the material. Its value is not defined as the stress at which an experimenter thinks a stress-strain graph departs from the straight-line condition; within fairly wide limits, it depends little on the sensitiveness of an extensometer, and it is easy in a commercial test to determine whether the proof strength of the material is above or below a specified value.

The proof strength is usually defined as the stress which produces 0·5 per cent. elongation after the load has been removed. For cold-worked or heat-treated steels, this elongation is excessive, and 0·1 per cent. should be used; a strong case could easily be made out for the use of this smaller value under all conditions. When the proof strength and its defining elongation have been fixed, a minimum chord modulus is also fixed, and this may be used to determine the section required

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Dr. R. M. Brown.

to limit the distortion to a permissible value which may be reckoned as safe. Proof stress, as a basis of the factor of safety, combines strength and distortion qualifications, but a factor of safety based on it would be valid for statical, or nearly statical, conditions, and it would not apply in a general case. There appears to be no definite relationship between proof stress depends on the mean stress of the cycle and on the shock strength, factors which must, in many cases, be the principal ones in determining the factor of safety to be used. When stress undergoes cyclical variations, the safe range of stress depends on the mean stress of the cycle and on the nature of the loading, and the effects of such factors cannot always be predicted with sufficient accuracy to permit of an estimated range of stress being used with entire confidence as a basis of factor of safety, unless the working conditions agree very closely with the experimental conditions.

Factors of ignorance, ignorance of hidden defects in material and workmanship, and of unknown loading contingencies, are much more difficult to estimate, and such considerations must continue to account for a considerable proportion of our factor of safety.

Prof. JOHN H. ANDREW, D.Sc.: I am pleased to find that the question of the factor of safety has been brought up for discussion. As a metallurgist, I rather favour Mr. Riddlesworth's definition, namely, factor of ignorance. It is only fair, however, to point out that the ignorance is not entirely an engineering factor, but is largely due to the steel-maker's inability to supply guaranteed sound material. If all steel members were homogeneous, and gave throughout their complete section the same tensile properties, then the engineer might conceivably lower his factor of safety to a comparatively small figure. He might indeed arrive at a sensible theoretical value for every class of steel. So long as steel or other metal members are sound, all is well, but, unfortunately, such is not always the case. Failure, when it does arise, is frequently due to some flaw, slight or otherwise, in the material for which

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no factor of safety will allow. For instance, if a test bar containing a slag patch at the surface of the constricted parallel portion be pulled in a test machine, a sliding fracture will usually be obtained, and consequently, a bad test result. If, on the other hand, the slag particle be in the centre of the test piece, there may be little or no difference in the test figures. If this example be applied to structural members, the same will apply; provided the flaw or inclusion be buried within the metal, no detriment may accrue, but if it be a surface effect, the matter will be different.

It would seem as if the allowance of a factor of safety were largely based on the fact that local defects may occur in the material employed. It is, in a word, a factor of probability, the probability of non-uniformity of the material. It is my opinion that no factor of safety can be sufficiently high for faulty material; if a member be flawed, it will inevitably break under almost any conditions of stress. Why then not calculate the factor upon the most reliable tensile property, employing a comparatively low figure, and instead of, when a material does fail, attributing failure to fatigue, admit that it is due in some way to a flaw or inclusion in the material?

I believe that, until the notched-bar test is included in every specification, there can be no thoroughly reliable method of ascertaining the true characteristics of any material. The notch bar appears to give a value which bears some relation to what might be expected in faulty material, for is not a surface inclusion similar in its effect to a small notch? I look forward to the time when notched tensile test-pieces, as well as shock tests, will be the order of the day. Then it may be possible to base a factor of safety on actual test figures.

Dr. J. Bruhn (Member): It is very useful to discuss, as Mr. Riddlesworth does, the problem of how, when we know the material, we can ensure that our structures have the required strength. For most kinds of machinery on board ship, the factor of safety principle may probably be used with as much justification as in the case of other mechanical engineering

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Dr. J. Bruhn.

problems. I do not think, however, that it is desirable to use the factor of safety method at all in connection with the structure of a ship's hull. In order that this method may be used with advantage, it is necessary to be in a position to—

1. Estimate the working loads.
2. Estimate the working stresses or deformations.
3. Know the limit of stress or deformation at which the structure will fail in such a manner that the safety of the ship is at stake.

None of these conditions is fulfilled in the case of a ship's structure. Take the strength of shell plating against bending between the frames. The load (say, water pressure) which may be considered a reasonable working load is unknown. It varies undoubtedly very much at different places of the shell. In the flat of the bottom under the fore part it will probably, when the vessel is striking a wave, be hundreds of times greater than it will ever be, for instance, in the vertical sides. The working stress and deflection cannot be determined in this simple case with any degree of exactness, even if the working load were known. The load at which permanent deflection takes place is usually much in excess of what could be considered a reasonable working load, and the load at which rupture would take place is enormously larger. If, therefore, a factor of safety were based on the failure by some permanent deflection, unity might be sufficient, seeing that a little permanent deformation in this case would not endanger the safety of the ship, as it would be a very long way from this load that actual rupture would take place.

Not even for ordinary longitudinal bending is the working load known, and the working stress cannot, therefore, be estimated. Consequently I think that it is misleading to speak of a factor of safety in connection with a ship's structure. I believe it is better simply to record scantlings in terms of size and arrangement of structure, and conditions as to loading such as draught, cargo, weather, etc. In that manner it will,

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Dr. J. Bruhn.
with sufficient experience, be possible to know what scantlings will give security.

It may be convenient, for the purpose of establishing comparisons, quite apart from factors of safety, to work with a stress figure, but it would then be desirable to select figures lying sufficiently far from those which might represent working stresses, to prevent the impression that the figures arrived at have anything to do with real stresses. The comparison of the effect of using materials of different qualities can, it seems to me, be established equally satisfactorily without the use of any factor of safety, but it has in any case to be so established, as knowledge of the magnitude of the factor of safety does not exist.

Mr. Riddlesworth mentions hoisting gear. For that I think it is also undesirable and misleading to use factors of safety. When such gear has once been tested to a certain load and a certificate issued, this fact will necessarily give donkeymen and others the idea that the gear is safe for lifting loads of a certain magnitude, irrespective of what wear might have taken place, and irrespective of the manner in which the gear is used. The load may, for instance, have caught somewhere, and the stress on the gear consequently be enormously higher than that due to the test load. The only reliable method of securing increased safety in connection with hoisting gear is to get those using it to examine it regularly for faults and wear, to test it themselves, and to understand how the gear is to be used without its being overloaded.

Mr. JOHN ANDERSON (Member of Council): The views put forward by Mr. Riddlesworth are undoubtedly correct in principle, but, considering that the actual strains on complex structures, such as ships and bridges, cannot be accurately calculated, even for hypothetical conditions, I think it would be a mistake to assume that, because a more or less definite value of elastic strength of material can now be obtained, it will be possible to eliminate what has been termed a "factor of ignorance." The so-called factor of ignorance is, in reality,

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a factor of experience, and, owing to the impossibility of prescribing actual conditions of service, I fear that, even with improved materials, it will not be possible to do more than judiciously reduce the ratio between assumed working stress and ultimate tensile strength.

Elastic limit and limit of proportionality are measures used by the metallurgist, but it is thought that neither of these limits can be determined by experiment on a structure. A designer would be more interested in permanent set of material, and it is doubtful whether, by experiment, he could say definitely, to within a ton per square inch, where permanent set actually takes place. It may be of interest for me to state that results of extensive experiments carried out on a ship recently, under static conditions, showed the measured strains to be about two-thirds of the calculated amounts, and I am informed that similar results have been obtained on bridge structures.

Mr. C. R. H. Bonn (Associate Member): It has been the fashion among those who would be considered up-to-date to ridicule the factor of safety. It behoves those among the critics who are scientific to supply us with something more useful before they condemn a constant which has served the practical engineer so well and so long, and the practical engineer should be sceptical so long as the scientists can supply him with no information other than that obtained from practical tests he himself originated.

Everyone will acknowledge that we are a very long way from discarding the factor of safety; all we can do at present is to rationalise it, and I see no attempt to do so in this paper. The so-called factor of safety is in effect a composite factor; it is the product of at least four factors, namely, those representing the true elastic limit, the character of the stress, the manner in which the load is applied, and lastly, the factor of ignorance; and let it be noted that this, the true factor of ignorance, should never be confused with the so-called factor of safety, which can only be called a factor of ignorance in

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Mr. C. R. H. Bonn.
so far as it is used to cover up an ignorance of applied physics. If this rationalised factor of safety is used, all Mr. Riddlesworth's fine points vanish into thin air. A point usually neglected is that due to the stress-hardening effect. Once a set is produced, an increasing force is required to increase the set further. A mild-steel structure is the safest that can be built; it will not collapse suddenly, unless there is some very defective member, but will settle. As this is the case, the last-named factor of ignorance in the rationalised factor of safety should be called the factor of fear, and where no great damage may be anticipated from collapse, can be neglected.

During the war, when it was impossible to obtain steel sections except for Government work, I was responsible for a large crane structure, built of bars dug up on the premises. In designing this I first allowed for corrosion, and then, owing to the dearth of material, took into account only the first three factors in the rationalised factor of safety. This structure swayed so much under test owing to jibbing that the first crane-man had to be assisted down and stimulated. Very soon all sorts of stays and guy ropes, never allowed for, were attached to this convenient structure, and at one time a load of two tons was actually applied horizontally to the head of one of the columns. Since then it has been systematically overloaded, but is still functioning. My motto was, "Never spare one extra rivet."

If anyone remains unconvinced that this factor of ignorance is a factor of fear, let him proceed to any of the main-road bridges on the Forth and Clyde Canal around Glasgow and watch the heavy motor traffic crossing and recrossing wood and cast-iron structures designed, over one hundred years ago, to carry horses and carts. Now, what would one fully reported failure in the case of one of these many bridges teach us? —merely that that which failed was defective.

Mr. Riddlesworth: I wish to thank the contributors to the discussion of this "provocative" paper, and while, as was

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to be expected, no finality has been reached, quite a number of definite facts have emerged.

Mr. Lockwood Taylor advocates, for the purpose of evaluating working stress, measurements of stress as against calculation. Presumably he refers to strain measurements, which, however carefully made, are subject to much criticism. Generally, they can only be carried out under casual conditions, and have to be converted to terms of stress by reference to a modulus of elasticity which can never be checked. Until these measurements can be made and repeated under any specified conditions, until it becomes reasonably certain that the strain measured along one particular line in the structure is truly representative, and until the value of the modulus of elasticity of the material, as built into the structure and as loaded as part of the structure, is known, it does not appear that much information of value in the present inquiry can be derived from them.

Mr. Lockwood Taylor and Mr. Adam refer to the fact that if approximately the same "allowance for corrosion" be deducted from the scantlings of a large ship and of a small one, the stress on the sections as thus reduced will be approximately equal. This view of the problem is of importance, and worthy of being emphasised. Mr. Lockwood Taylor's suggestion that a long strut might safely be allowed to buckle under an impulsive load is somewhat daring, and would not commend itself to the one who had to attend the trial of a structure so loaded.

Mr. Cole refers to our very limited knowledge of the properties of such a structure as a ship, and even of the properties of the materials of which it is constructed. Until that knowledge grows, we can only ensure safety by adopting a very large factor of ignorance. Mr. Cole's quotation of the results of calculation on bulkhead stiffeners is somewhat unfortunate. Perhaps it would have been better not to expose to the public gaze our family quarrels about the amount of associated plating that may legitimately be included in stiffener calculations. His statement that for ship work, failure takes the form of excessive

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Mr. W. H. Riddlesworth, M.Sc., M.Eng.
distortion, defined as a permanent distortion of some, as yet, unspecified amount, and not as fracture, is interesting and important. If universally agreed to and fully acted upon, the result would be the general use of material with a high elastic limit and a very considerable reduction of scantlings, and at the same time the deflections experienced in ordinary service would be greatly increased. I think that fuller consideration will show Mr. Cole that Table I is in order in respect of the two items he names, but that fracture of long columns should have been made to depend upon U and E.

My use of the term "elastic limit" is justifiably open to criticism, but for the sake of simplicity I used the term as a convenient name for the stress at which permanent set becomes measurable by ordinary workshop appliances, well knowing that ultra-refined methods reveal many discrepancies from the simple behaviour predicted in most practical applications of the theory of the strength of materials.

Mr. Adam, in effect, misquotes me. My object is to obtain an agreed-upon specification of the form of failure to be provided for, and the introduction of an "absolute" failure complicates matters most undesirably. Presumably Mr. Adam means that, in the case of a ship designed to avoid failure by excessive distortion, the ship would not necessarily be lost even if excessive distortion did occur. Granted, but then she would have failed to carry out the specification to which her designer was working. On page 333, I refer to the necessity of specifying the induced stress in addition to the permissible deflection in structures when the distribution of material is of importance, *e.g.*, in beams, etc.

Dr. Brown agrees with the simplification of the problem that is adopted in the paper. We might extend very largely the list of qualities of material on which failure depends, but if we could establish a logical procedure by fully considering the simplified problem, it would be by no means difficult to insert appropriate strength values allowing for the effects of variation in stress, in temperature, or in any of the other causes affecting the strength of the material. Dr. Brown's example of a roof

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Mr. W. H. Riddlesworth, M.Sc., M.Eng.

truss, in which one member had considerable distortion, appears to indicate that the problem of making all members of a complex structure equally liable to fail, has not received the attention it deserves. Obviously, uniform strength, and that the minimum necessary, leads to the most economical use of material. Dr. Brown's restatement of, or substitute for, Hooke's law is of interest, especially in its implications about the beam theory. The idea of recording and using "proof stress" is of value, and could a general agreement about the permissible elongation be arrived at, progress might follow.

Prof. Andrew deals principally with the effect of hidden flaws in the material. On page 332 I refer to the logical evaluation of probabilities. The probability that a hidden flaw will occur in a member cannot be evaluated; but if it were found that a notched-bar test, simulating the effect of a small flaw, indicated, *e.g.*, a reduction of 50 per cent. in the ultimate strength, then there would be a quite good case for the inclusion of factor 2 in the factor of safety, to take care of that particular item in its total value.

Dr. Bruhn, whom we regard as an authority on the strength of ships, appears to be in a pessimistic mood about technical progress. His record of scantlings in terms of size and arrangement of structure, etc., puts us back to the days of . . . Rules for the Construction of Steam Ships, in which there was no logical basis, but a collection of scantlings based upon a, no doubt, wide experience. As far as the use of materials of varying qualities is concerned, my suggestion is that it is necessary to define the form of failure to be anticipated, thence determining the quality of the material on which failure depends, and then choosing the material with that quality most highly developed as the most desirable. Thus far the factor of safety need not be considered, and if it be merely a case of comparing a mild-steel structure to "tabulated scantlings" with one built of some possibly better material, simple modification of the scantlings in inverse proportion to the respective values of the quality on which failure depends is indicated. But it might be desirable to go further,

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to see that the design was homogeneous, and that full advantage had been taken of the qualities of the material used; for example, the better quality material might be less liable to defects or to decay, either forming a justification for a reduction of the factor of safety and of the scantlings.

Mr. Anderson, who has probably more experience than most in the use of one of the better quality materials, is obviously still without a logical guide to its use. To "judiciously reduce" is sound practical politics, but it lacks the logical foundation that is so desirable. It is interesting to learn that in both bridges and ships measured strains are only about two-thirds of the calculated strains. Some of this is no doubt due to the value assumed for the modulus of elasticity, but a fuller explanation is very desirable.

Mr. Bonn appears to find in this paper an attempt to ridicule the factor of safety; the intention, at any rate, was to indicate some consideration which should govern its magnitude. Mr. Bonn's crane structure was obviously a case of making the best of things as they were, and was not the result of any logical and well-thought-out design, but, like many other makeshifts, it worked in a way. The bridges referred to are examples of design where too high a factor of safety has been used, and owing to the unnecessarily heavy construction a heavy burden of capital costs has been carried by the owners for nearly 100 years.

The general result of the discussion may be well summed up in the following modification of words written by George Bernard Shaw in an entirely different connection. The end of the matter will be in the doing of things, and we shall find out how to choose and use our materials by the old method of trial and error, and not by waiting (and working) for a completely convincing prescription of the reasons.

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THE PRESSURE DETECTOR.

By NORMAN YOUNG,
Member of the Institution.

10th January, 1928.

THE Pressure Detector is a form of indicator which operates on entirely new lines. With this instrument, the aim is to obtain accurate pressures, at selected points in any cycle of varying pressures, and having determined these, to plot them in curves on an angular base. The apparatus consists of a magnetic valve of special construction, and a variable contact-maker which switches on electric current to the valve at a selected point of the cycle. The valve opens magnetically for a very short period of time, during which the engine cylinder, or other source of varying pressure, is put into communication with a pressure gauge, located on the other side of the valve. The contact-maker switches on the valve at the selected point every revolution. After two or three revolutions the pressure gauge becomes steady, and registers, in a static manner, the pressure at that point. If a series of readings are obtained at points, say, five degrees apart, they will, when drawn out, give complete curves of the pressure cycle.

The power required to lift the valve is independent of the pressure. Once the gauge has settled at the steady reading, the valve is always operating at the instant when it has equal pressures above and below. It follows that the time intervening between the switching-on of the current and the lifting of the valve is constant, and the timing of the valve uniform. The friction of the valve is uniform and very low, and the lift is only $\frac{1}{64}$ inch. There is no distortion of curves due to

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driving gear, and no loss of pressure due to friction of piston and recording parts.

The pressure detector opens up new fields of investigation, but it must be regarded as a co-worker, and not as a rival, of the indicator. It does not solve the problem of recording varying pressures in very high-speed reciprocating engines.

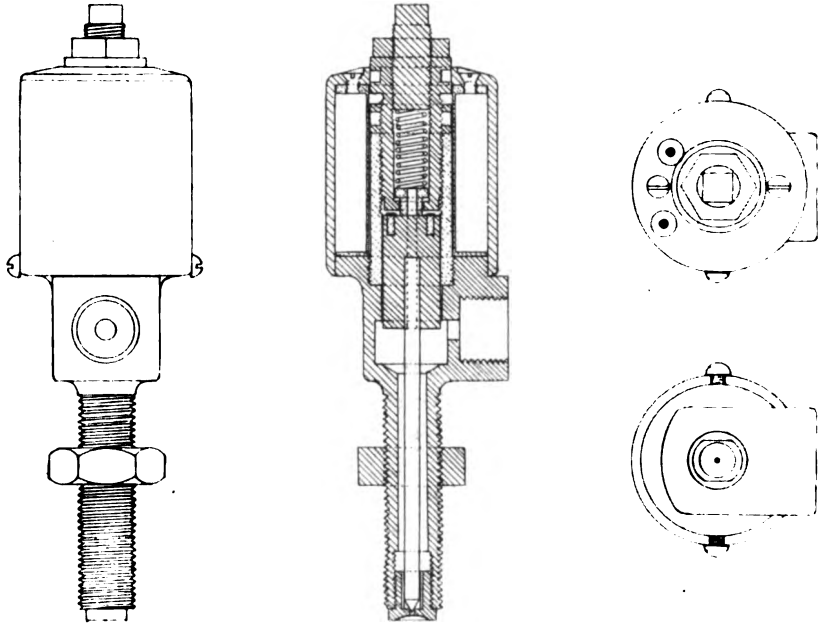

Fig. 1.—Pressure-Detector Valve.

Figs. 1, 2, and 3 show the special magnetic valve. The moving valve is of the spindle type, and is held on its seat by an adjustable spring. The dead weight on the valve is about 8 lbs., which is sufficient to resist a pressure of about 1,500 lbs. per square inch on the small area of the valve. The head end of the spindle is fixed into a small mild-steel cylinder of $\frac{3}{4}$ inch diameter. This spindle, together with the cylindrical armature, is the only moving part. Above this armature, and separated from it by an air gap of $\frac{1}{64}$ inch, is an adjustable magnet pole.

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If the current were to remain on for a length of time, the pull across the gap would be 40 lbs. The time of contact of the contact-maker is, however, so arranged that the current is cut off just at the instant that the valve lifts. It is of great importance that the period of opening should be of minimum duration, in order that little or no pressure change may occur during the time the valve is open. The difficulty of opening and shutting the valve in a suitable fraction of the cycle, limits the application of any apparatus of this description for high speeds. The armature is encased in a liner of brass, and

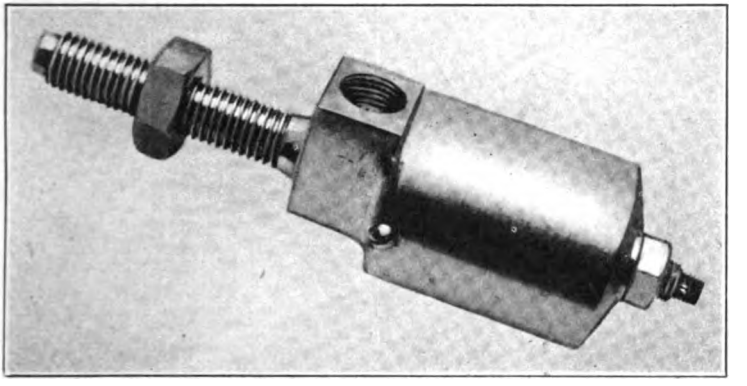

Fig. 2.

enclosed in a gas-tight chamber. As the power to move the valve is produced inside the chamber, no packing gland is required, and so a very simple, tight, and almost frictionless valve results. Around the brass liner and enclosed in a mild-steel casing is a solenoid coil, which is wound to suit lighting supply voltages, and is suitable for working on direct current only.

The operating current is about $\frac{1}{10}$ ampere. The valve seat, which is renewable, and the spindle are made of tempered steel, but for particular purposes they may be made of special heat-resisting steel. The valve body is prolonged so that the seat may be carried right into the point where the

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varying pressure occurs. This feature is also a necessity when the apparatus is to be used for gas sampling. A point in favour of the detector when used on very small cylinders is that it adds nothing to the clearance volume when in action.

Fig. 4 illustrates one form of contact-maker. A small contact disc is driven from the crankshaft, or, in the case of a four-stroke engine, from the camshaft. The disc is made in two parts, and by moving these together or apart, the arc of contact can be varied to suit the speed. As the time of contact required to overcome the magnetic lag, before the valve opens,

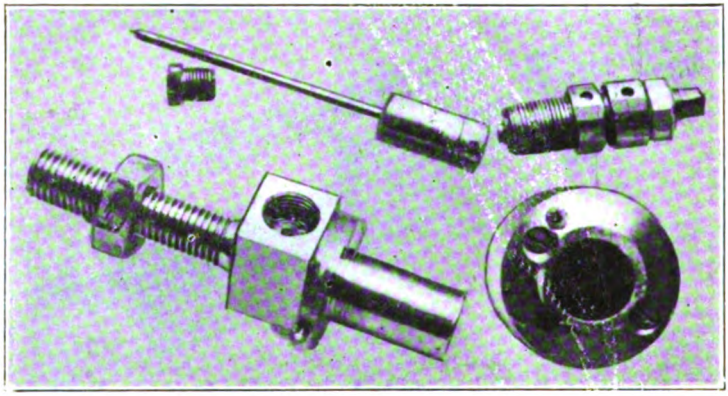

Fig. 3.

is constant, it is necessary to have a greater arc of contact for higher speeds. The period of contact is about $\frac{1}{80}$ second. The valve has operated successfully to over a thousand times per minute. The electric circuit is completed every revolution on two spring contacts, carried on an insulated disc and communicating with two fixed slip-rings. This disc can be revolved into any desired position, and held there by means of a spring locating-pin, which engages in a series of holes spaced five degrees apart.

Fig. 5 illustrates the general method of setting up the apparatus. The valve is shown fixed into the usual $\frac{3}{4}$-inch indicator tapping. The current passes through the contact-

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Fig. 4.—Pressure-Detector Contact-Maker.

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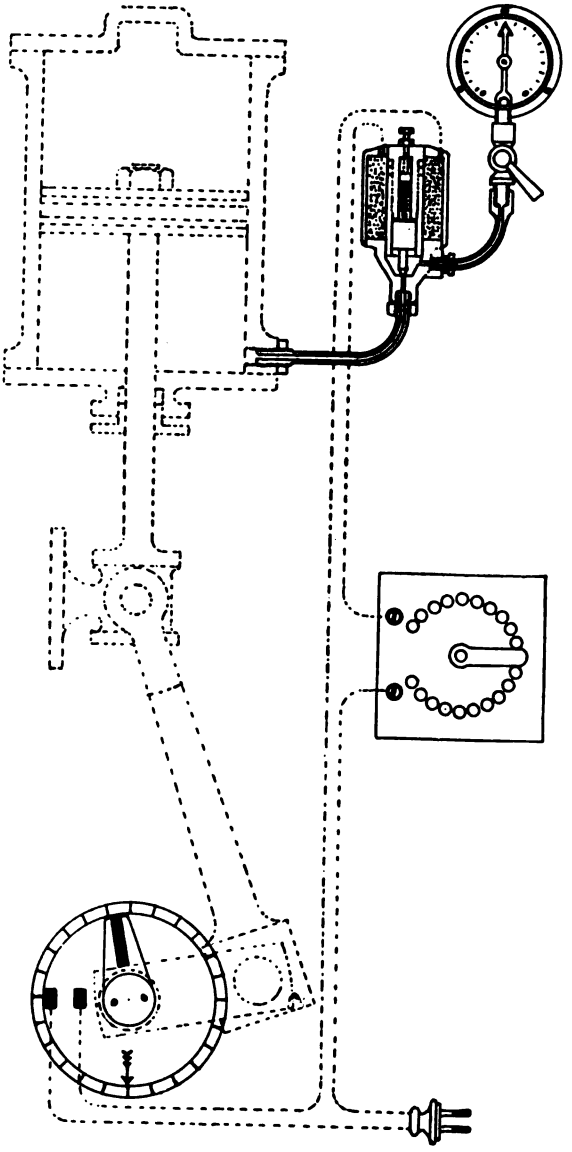

Fig. 5.

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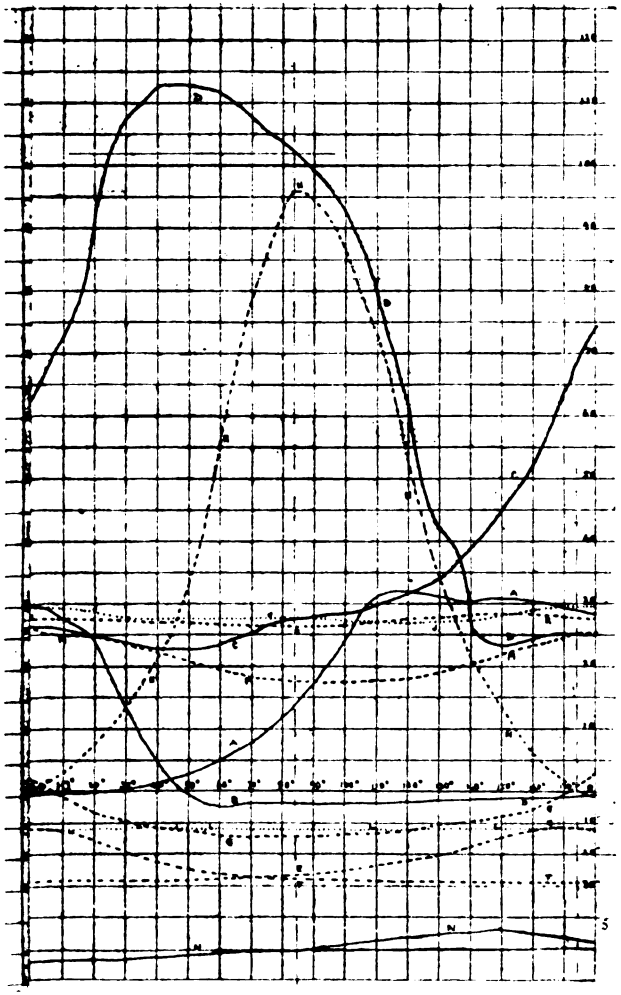

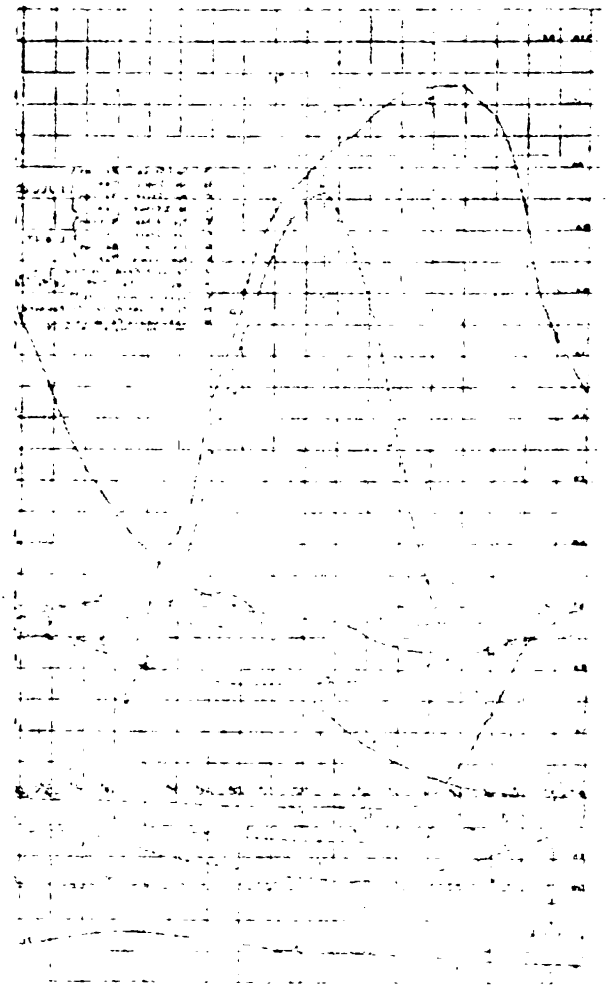

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maker, the valve, and a variable resistance in series. The function of the resistance is to adjust the time of opening to the minimum. It effects this by reducing the current to such a strength that it is just sufficient to lift the valve and no more by the time the contact breaks. Minimum timing can also be secured by adjusting the halves of the contact disc; but it is more readily done by means of the resistance.

The procedure is very simple. The apparatus is plugged into any lighting supply, up to 250 volts, and the contact-maker set to zero. If a variable resistance is in use, this should be adjusted to a point where one step more would cause the valve to stop operating. If the apparatus be allowed to run for a few revolutions, the gauge will become steady, when the reading may be noted and the contact-maker advanced five degrees. Readings should be taken at five-degree intervals till the cycle has been completed, and it should be possible to do this in about 12 minutes. It is seldom that accuracy demands readings oftener than five degrees apart. The load and speed should, of course, be steady while the readings are being taken. When drawn out on an angular base, these readings will give a good average curve of the pressures during the cycle. In cycles where there is a considerable range of pressure, it is advantageous to change the gauge to a more sensitive one for the low-pressure readings. As the curves are plotted from the readings, it is possible to attain greater accuracy than when the pressures are taken from the curves, as with the ordinary indicator. In drawing the curves, the scale chosen should approximate to that of the gauge used. In the case of a mercury column, for instance, this would be two inches equal to one pound. The applications and limitations of the pressure detector will be best explained by referring to specimen curves taken with the apparatus.

Fig. 6 shows a set of curves which give a complete analysis of a 160 horse-power two-stage air compressor, compressing to 100 lbs. per square inch, at a speed of 275 r.p.m. Curves are shown, taken from both ends of each cylinder, for light as well as full load. The pressures of delivery into the intercooler

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from the first stage, and entry to the second stage from the cooler, are included, as is also a curve of the forced lubrication pressure. The angle basis of all these curves is referred to the one contact-maker, so it is possible to ascertain what occurs in every part of the compressor at any instant of the cycle. At the foot of this illustration is a curve, drawn to a larger scale, which gives the pressure variation in the crankcase. This was obtained by using a water gauge in conjunction with a detector. The maximum variation in pressure is of the nature of $\frac{1}{300}$ lb. per square inch. The fact that this curve rises to about the same amount above the base line as it falls below it, would seem to indicate that the actual pressure is being accurately obtained. This is a good example of the utility of this apparatus in determining extremely low-pressure variations.

In Fig. 7, part of the same data is laid out on a greater pressure scale. The curves representing first-stage deliveries and second-stage suctions, as well as the intercooler pressures and oil pressures, are here redrawn to a scale which allows the variations and losses of pressure to be more accurately studied.

One of the difficulties met with, when pressure cycles are investigated with this apparatus, is that of accurately placing the top and bottom centres. If the data are to be worked up in the form of power diagrams, it is, of course, necessary that these points should be closely located. Perhaps the best method is to locate the centres from consideration of a correlated set of curves. In the case of a compressor, the centres will always be near those points in the cycle where the cylinder and receiver pressures approach coincidence. At the point where the centre occurs, the curve usually assumes an ogee form; that is, the curvature changes over from a curve having its centre on one side of the line, to one centring on the other side. The centre can generally be fixed at the point where the change of curvature takes place. The position of the centres in this case can also be confirmed from the position of the top of the second-stage light-load curve in Fig. 6. Here

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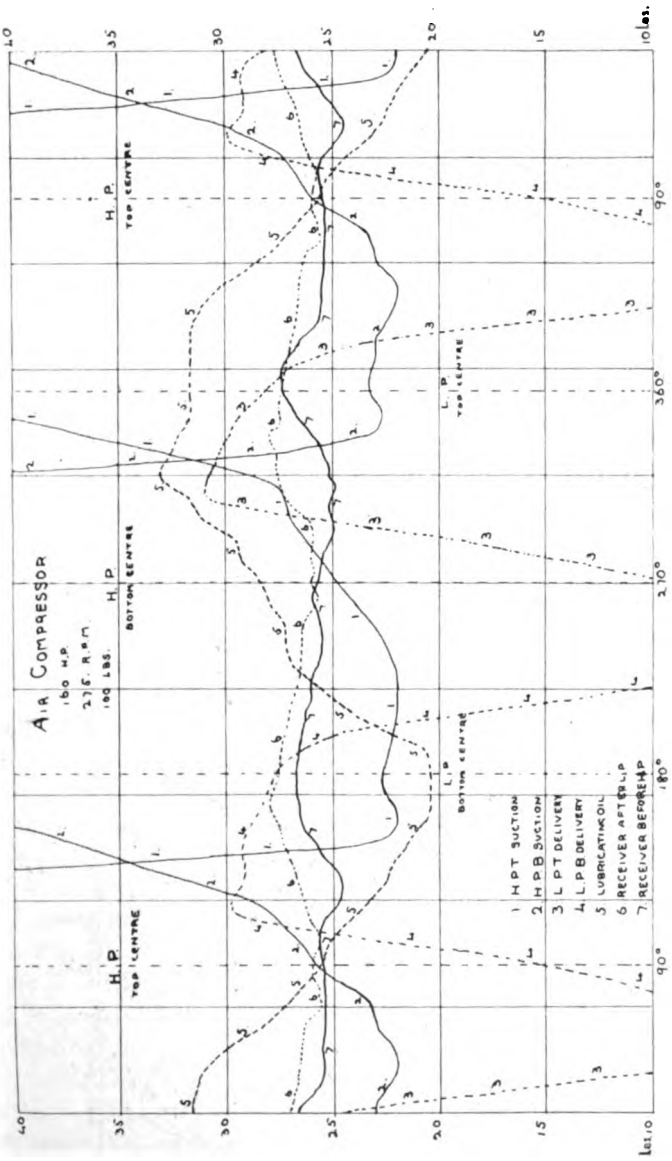

Fig 7.

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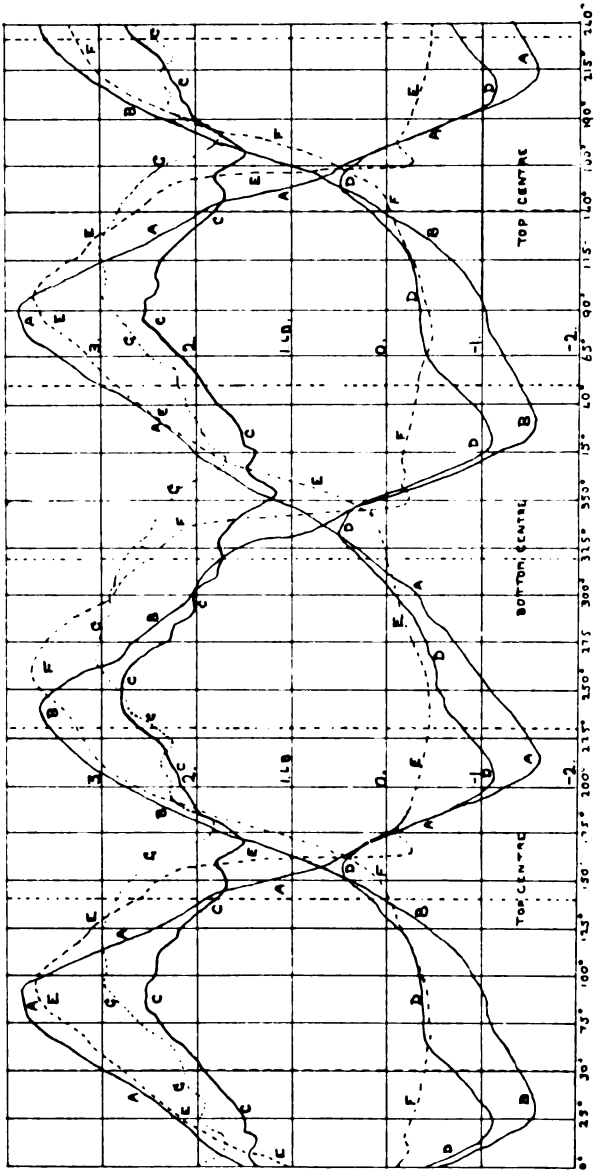

Fig. 8.

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compression and expansion go on without the delivery pressure ever being reached. The top centre may be located close to the point of maximum pressure.

In Fig. 8 are drawn two sets of pressure curves from two different scavenging pumps belonging to two similar Diesel engines, the second pump having been designed after data had been taken from the first by means of the detector. The curves taken from the first are drawn lines, and from the

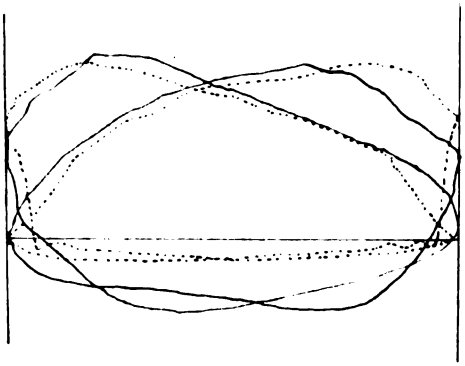

Fig. 9.

second, dotted lines. The saving is 34 horse-power, and there is besides an increase of scavenging pressure of over ½ inch. It may be noted again that the centres on these curves are located on points where curvature changes, and where the pressure across the valves approaches zero. Power diagrams, Fig. 9, constructed from the same data, show the improvement in a more familiar guise.

In Fig. 10 a few more Diesel-engine pressure curves are given. Curve B is that taken from the cylinder of a two-stroke engine, and is drawn to a scale of 100 lbs. to an inch; C gives the scavenging receiver pressure for part of the stroke; D shows the variations occurring in the exhaust pipe; and curve A illustrates the low-pressure part of the Diesel cycle, taken to 200 times the scale, and drawn to 100 times the scale of curve B. Once the low-pressure part of a cycle is known,

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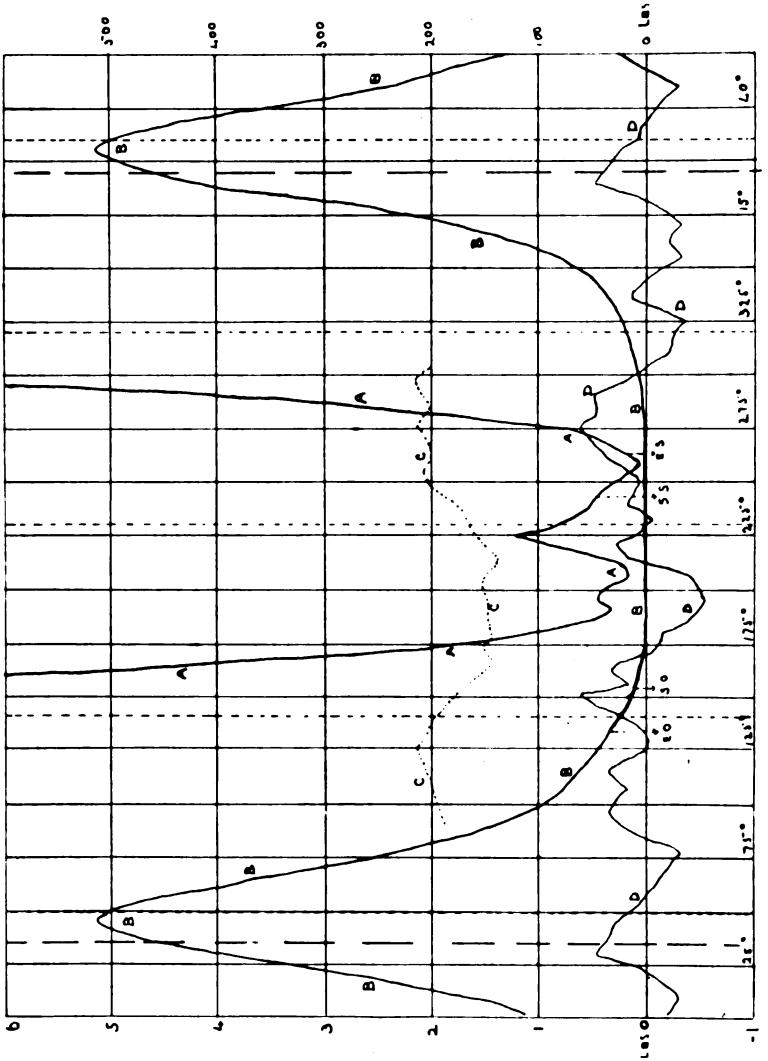

Fig. 10.

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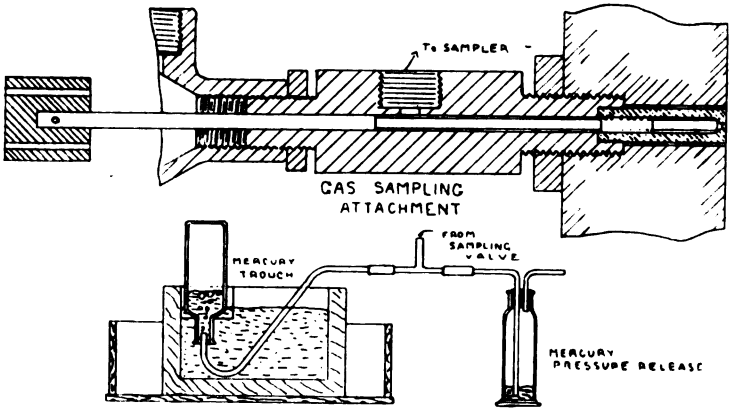
it is quite safe to investigate this, with a mercury column, even in a high-pressure cylinder. From all these curves, it is very interesting to study the way that even small pressure peaks in the exhaust curve coincide with peaks on the other curves, in some cases right back to the scavenging pump cylinder. The reasons for the peak in the scavenging line A become apparent when studied in relation to the other curves. It was for the purpose of detailed investigation of scavenging functions that the detector was first developed, and for such work it has proved highly successful.



GAS COLLECTING GEAR

Fig. 11.

About two years ago it was suggested that the detector might be used for securing exhaust-gas samples in the case of two-stroke engines, by selecting instants when the pipe was likely to contain undiluted exhaust gases. The research staff of the Royal Technical College have bettered this, and have made use of it to secure samples from various parts of the engine at every part of the cycle. By the courtesy of the research staff I am able to give, in Fig. 11, the gas-sampling attachment used at the College, and also a diagram showing the method adopted of collecting the gas samples. The

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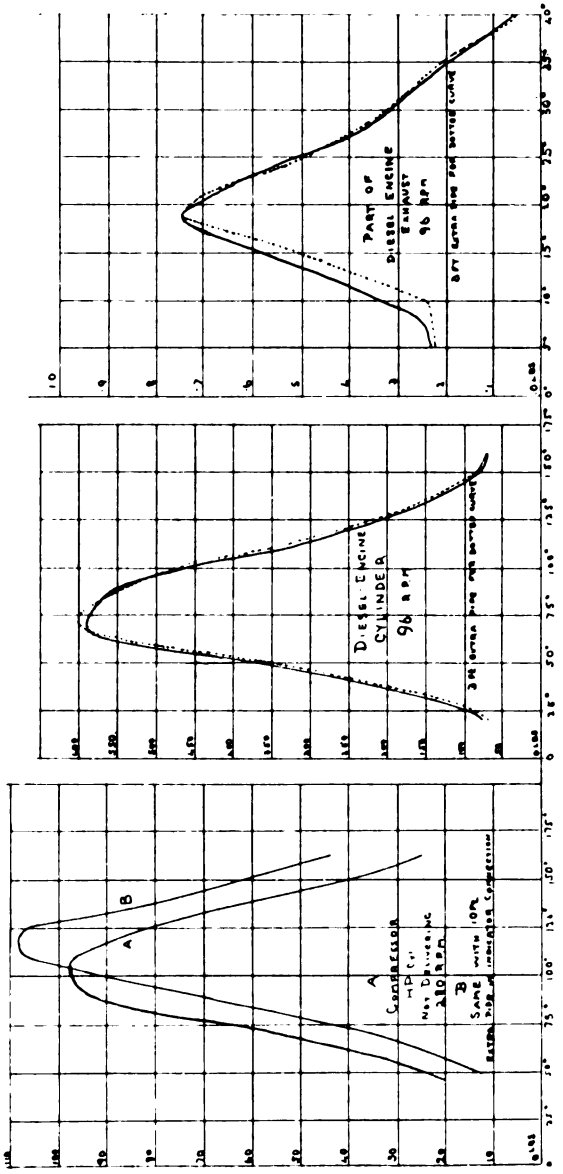

Tests Showing Effect of Long Indicator Connections

Fig. 12.

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apparatus has proved itself to be quite useful for this purpose at 500 r.p.m., and when special heat-resisting steel was utilised in the valve and seat, a series of samples was even taken from the hot-bulb of a semi-Diesel engine.

In common with the indicator, the detector will not correctly indicate the true pressure in the source, if a long connecting pipe is introduced between the magnetic valve and the part being tested. Curves A and B, Fig. 12, show the lag and increase of pressure obtained by inserting 10 feet of $\frac{1}{4}$-inch piping in the case of a compressor running at 280 r.p.m. The second set of curves refers to a Diesel engine running at 90 r.p.m. In this instance the pipe was three feet long. As the lag seemed to be the same all the way up the curve and independent of pressure, the third set was taken from the exhaust pipe, and seems to bear out this point. The increase and lag of pressure in both cases also seem to verify one another, and to lead to the expectation of an increase in all cases. It happens, however, that, although the speeds of the two engines are as three to one, had the curves been drawn out on a time instead of an angle base, the rate of increase of pressure would have been found to be similar in both cases. At the Royal Technical College it was found that, with a Diesel engine running at 500 r.p.m., and having a rapid change of pressure, the full pressure never reached the end of the pipe, so that the pressure shown was lower instead of higher than normal.

It would appear that air waves have a definite rate of flow. When the pressure cycle rate of change is less than this rate of flow, the momentum of the gas causes an extra pressure by compressing the gas at the end of the pipe; but when the rate of change is more rapid than this rate of flow, the wave may not reach the end of the pipe before the ebb commences. For this reason, the detector valve is now designed to go as far as possible into the source of variable pressure. With this long valve and a minimum of pocket space in front of the seat, it is hoped that gas sampling will be possible without any special adapter. Any length of piping can be used between the

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valve and gauge. Improved readings can often be secured if, by fitting a long connecting pipe, the gauge is fixed up in a steadier and more approachable position.

To sum up: the accuracy of the readings depends on minimum time of opening, on perfect tightness of the valve and gauge connection, and on close connection to the source. The pressure range is only limited by the design, and can be made to any requirement. The standard design will work to over 2,000 lbs. per square inch. No adjustment of the instrument is required for pressures up to 1,500 lbs. per square inch. The power required to operate the valve, as already pointed out, is the same for all pressures. The useful maximum speed at which the apparatus can be relied on to give accurate results is about 500 r.p.m. The limiting factor is not so much one of revolutions as of maximum rate of change of pressure. For tracing out gradually-changing pressures, it might prove useful at much greater speeds. The valve as now made will operate at 1,000 r.p.m. with contact made on the contact-maker for 70 degrees of the revolution.

Discussion.

Mr. JAMES SMALL, B.Sc. (Associate Member): The study of what happens to the working substance during a cycle in a reciprocator is becoming more and more searching, and modern methods of thermodynamic analysis are demanding from the indicator extreme accuracy in its record of the condition of the working fluid at every point in the cycle. Even where less is looked for from the indicator, high speeds combined with high temperatures have been raising doubts about most of the existing methods of indicating. The principle which Mr. Young has used in designing his pressure detector gives promise of affording a more reliable record at fairly high speeds than has hitherto been obtainable from any apparatus of equally simple construction.

When the standard pressure detector of Mr. Young's design was unobtainable, a rough instrument was made under Prof.

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Mr. James Small, B.Sc.

Goudie's directions in the Engineering Laboratories at the University. He turned his attention to the matter to which Mr. Young refers on page 364, namely, the difficulty of identifying any particular recorded pressure with the corresponding position of the piston. This depends on a knowledge of the time elapsing between the making of electrical contact and the lifting of the valve. At Prof. Goudie's suggestion, steps were taken to measure this time lag under different conditions. An existing piece of apparatus was accordingly modified to serve this purpose. The complete valve fitting was carried on a slide rest, driven by a screw alongside a drum which had a sheet of indicator paper wrapped round it. A light rod attached to the bottom end of the valve-needle operated a small pencil-lever so arranged that when the valve was closed the pencil point bore lightly on the paper, describing a helical line when the drum was rotated. Also carried on the slide rest were two insulated flat springs, one above the other, acting as an electric key. The lower spring carried another pencil point touching the paper so lightly as not to describe a line. When the drum was set rotating at a known uniform speed, the upper terminal spring was brought down sharply into contact with the lower. A line, therefore, commenced to be described on the paper at the instant of electrical contact. When the valve commenced to lift, the other line broke off. The distance between the commencement of one line and the end of the other gave a measure of the time elapsing between the making of the electric circuit and the lifting of the valve. The apparatus is, of course, capable, with slight modifications, of measuring other time elements in the working of the instrument.

The results are of interest as representing the general characteristics of any similar electrically-operated valve; but it would be well to make it clear that they were not obtained from a standard instrument, and that the chosen conditions under which the measurements were made exaggerate the characteristics of the valve. It is hoped in the course of time that some similar measurements will be made on a

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Mr. James Small, B.Sc.

standard instrument which has been ordered from Messrs. Elliott Bros.

The state of compression of the spring of the detector seems, as might be anticipated, to have a marked effect on the time lag, the voltage of supply at the solenoid being kept constant. It might be argued with reason from the form of the curve of current growth in a simple resistance, Fig. 13, that the greater the magnetising current required to overcome the compression of the spring, the greater will be the time necessary for its growth. The results obtained are plotted in Fig. 14. It would appear that the required angular advance of the point of

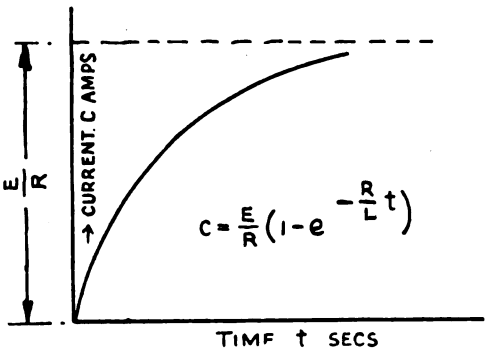

Fig. 13.

contact varies considerably with different amounts of compression on the spring. Any alteration in the value of the variable resistance affects the supply voltage and also the lag, and for this reason it is necessary to keep it constant during the time of indicating the complete cycle. As would be expected, the initial lag is found to vary considerably with the gap between the core and armature. Although the curve showing the results of measurements made under these conditions may only be of academic interest and is on an exaggerated scale, it is given in Fig. 15.

In the course of the remarks which Mr. Young added to the reading of his paper, he showed that when the procedure for adjustment which he describes on page 363 is followed, the

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opening of the valve takes place just when electrical contact is broken. It is hoped to verify this, and if this holds at all times under working conditions, then the elaborate analysis of curves which he describes for obtaining the positions of the dead centres should be happily rendered unnecessary.

A matter of importance is the duration of the interval elapsing between the instant at which the valve leaves its seat and the instant at which it returns to the seat. This is made up chiefly of (1) the time of lifting, and (2) the time of

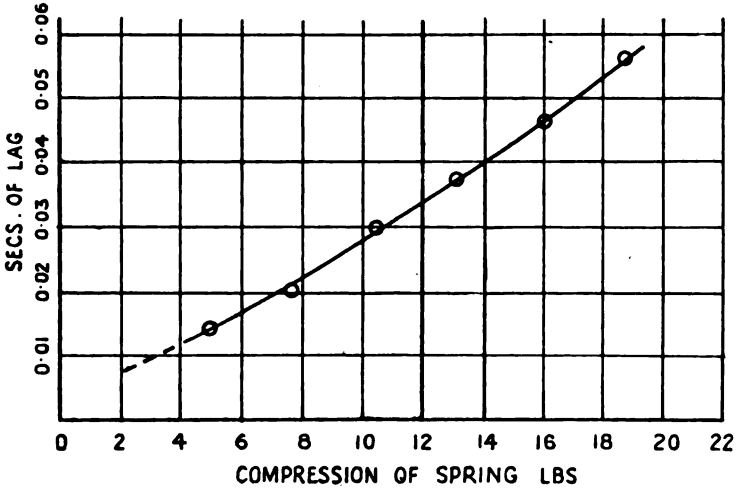

Fig. 14.

closing. An estimate of the latter quantity may be made from ordinary dynamical considerations on certain assumptions. The armature and valve spindle in the standard instrument together weigh about 3 ozs. Let us suppose that immediately the electrical circuit is broken the spring forces down the valve with a thrust of 8 lbs. (since 8 lbs. is the figure mentioned by Mr. Young in his paper), and assume that there is no friction and no residual magnetism in the core. Under these conditions, the time taken for the valve to drop through $\frac{1}{64}$ inch is of the order of $\frac{1}{120}$ of a second. On an

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Mr. James Small, B.Sc.

engine working at 500 r.p.m., this time interval corresponds to a crank displacement of four degrees. It is reasonable to assume that the duration of the opening process is of the same order, and so it would appear that the total period during which the valve is open is not inconsiderable when the gap is $\frac{1}{64}$ inch. I take it that the work at specially high speeds, to

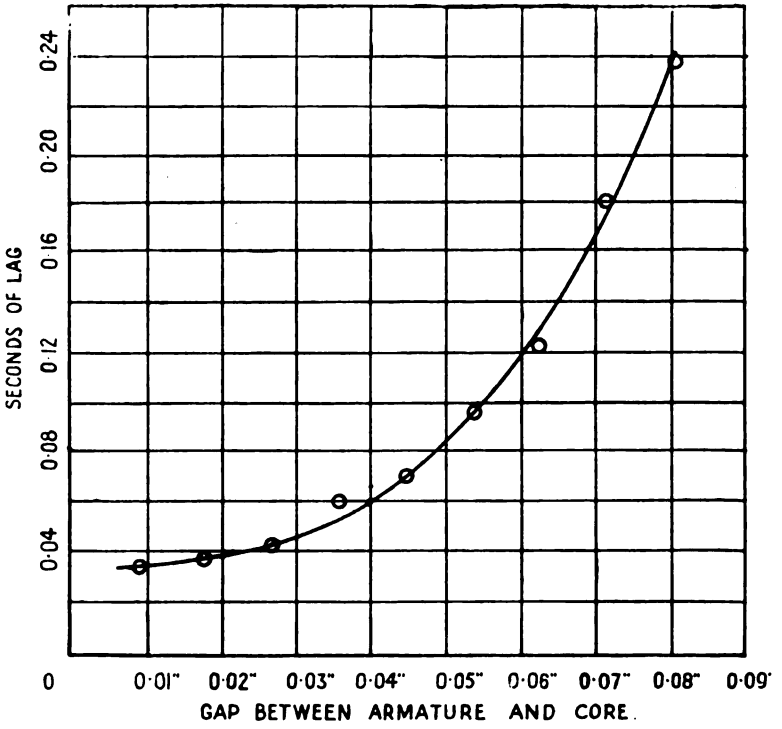

Fig. 15.

which Mr. Young refers, was carried out with the working gap at the valve less than $\frac{1}{64}$ inch. This is a matter of some importance from the point of view of any thermodynamic analysis which may depend on the accurate indication of a prime mover. If it can be shown that reducing the gap does not impair the record of pressure, then advantage of the

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smaller interval of opening should be taken for accurate records even at speeds which are not specially high.

The curve of displacement of the valve, plotted on a time base or a crank-angle base, will probably assume a form like that given in Fig. 16. The tendency will be, it seems, for the pressure gauge to record the final pressure falling within the interval for which the valve is open, rather than the average pressure. Opening takes place slowly under the action of a force which grows from zero, but the valve speed at the point of closing is comparatively high.

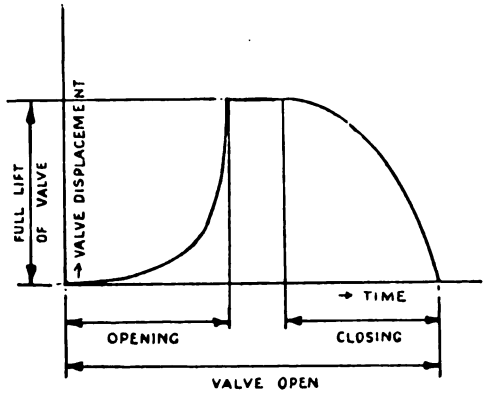

Fig. 16.

These remarks are concerned with an examination of certain details of the operation of the valve, because those who are interested in engine research are keenly anxious to obtain a *simple* instrument of precision, and are obliged to examine an instrument like this from that point of view. There is no doubt, however, that Mr. Young's instrument does what he modestly claims for it, is simple to use, and has great advantages over the ordinary forms of indicator in many of its applications.

Mr. C. R. H. Bonn (Associate Member): Apart from the inspiration which lies behind this invention, its development

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Mr. C. R. H. Bonn.

is a record of much thought and persistent effort. Mr. Young has been so candid in stating the limitations as well as the possibilities of his pressure detector that it is very difficult to ask any questions. He says the limiting speed at present is 1,000 r.p.m. Now modern motor-car engines run faster than this, and it seems to me that if the detector could be developed so that it might be applied to motor-car engines, much useful information would be obtainable. I have had the privilege of seeing this apparatus working, and it is rather striking to witness it registering the pressure at the low end of the cycle of a high-pressure cylinder on a water gauge, which remains absolutely steady. I think the possibility of using gauges which are best adapted to the particular range of pressure at the various points of the cycle, is one of the most important features of this piece of apparatus, and have no doubt it will be extensively used in the future in both research and practical work.

Mr. JOHN S. BROWN, M.B.E. (Member): Through the generosity of Mr. Young, one of these instruments has been at the disposal of the engineering laboratory of the Royal Technical College during the past three years, and it has demonstrated its value both as a pressure detector and as a gas-sampling valve. The open nature of the scale in the pressure records during the exhaust and scavenging of an oil engine has provided results of great interest, and has been used as a check on the accuracy of other forms of indicator. Further, in the field of gas sampling, it has been found possible to trace the progress of combustion in the cylinder of an engine operating at 500 r.p.m., which is to be regarded as a matter of distinct novelty and importance. This work was referred to in the course of the lecture, where slides amplified the illustrations given in the paper.

Here it will perhaps be useful to enlarge on certain practical details arising in the course of our experience, and which require attention to obtain consistency in performance. Thus it is obvious that the valve must be perfectly gas-tight when

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shut, for any leakages would have the tendency to alter the instrument to a simple throttling device, in which circumstance the pressure reading would become the time average of the pressures over the whole cycle. This would have the effect of giving low readings in the high-pressure region, and high readings with low pressures. But it is a simple matter to check that the valve is tight. This is done by taking a pressure reading in the high-pressure region of the cycle, and then cutting off the supply of current to the valve; in this condition the pressure should remain steady. Some little trouble may arise in obtaining this result, but it is all a matter of obtaining a proper seating for the valve; and it is quite useless to proceed until this leakage test is passed satisfactorily. Another point is that, theoretically, the valve operates across zero pressure-difference, and should, therefore, require a constant current at all points in the pressure scale; but there have been occasional experiences where the adjustment of the circuit at a low pressure has failed to give actuation of the valve at the higher pressures. The change in the conditions is quite small, and has been met by moving the rheostat by one step, although it is not clear why this should be necessary.

Again, when the instrument is being used for taking gas samples, it will be understood that the valve must be in the open and not at the end of some branch pipe, for the introduction of a branch pipe will only result in the sample being taken from the gases compressed into this pipe at the time of maximum pressure in the cycle. Even when the valve is arranged, say, at the surface of the combustion chamber in a Diesel engine, it has still to be accepted that the sample is only representative of what is occurring at one point in the cylinder. Here interesting results have been obtained in an engine where the fuel was injected into the cylinder through a flame-plate of the pepper-box type, this flame-plate being slightly rotated between successive tests. It was found that the combustion proceeded more rapidly in the zone of a fuel jet than in the space between, and it is evident that the com-

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Mr. John S. Brown, M.B.E.

bustion does not proceed uniformly throughout the cylinder. At different times a number of such special valves have been made in the College and actuated by Mr. Young's apparatus, and it may be noted that it is only with the use of Hadfield's "Era" steel that their life has been satisfactory. The earlier valves made from ordinary steels failed by burning or buckling with a very short period of service.

In bringing forward these results, I wish it to be clearly understood that they do not restrict the usefulness of the instrument, as they are only typical of the necessary precautions which arise with any apparatus which is to give accurate results. Further, I regret that the absence in America of Dr. T. W. F. Brown has prevented his bringing these points forward, for it was at his hands that the above experiences were obtained. But those who are interested in further details of his work will find a complete description in a thesis* which is on file in the University library.

Mr. Gilbert Austin (Member): The most clever things are the simple things nobody else has thought of, and Mr. Bonn has expressed my own views as to the utility of this simple little instrument. It is, of course, not intended for a fluctuating load, but it opens up possibilities of revealing working conditions in a steadily-loaded engine, on test or on service, with a degree of accuracy and ease of application not hitherto possible.

I understand from the discussion that for high-speed engines it would be desirable to get the valve to open and close with even greater rapidity, and I would suggest that attention might be given to reducing the inertia of the moving part and of the operating coil. I imagine the coil is worked too economically, and I think that by allowing a larger current to pass for a shorter time this result might be attained. Any tendency to spark at the contact maker may be quenched by shunting the coil with a condenser.

* "The Combustion Processes in Diesel Engines," 1927.

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Mr. Norman Young.

Mr. YOUNG: Mr. Small refers to the relation which points on curves bear to the contact-maker. The valve may be taken as opening at the instant when current is broken, and the time it is open has been definitely measured. The time from the first rising of the valve to the final return can be made as short as $\frac{1}{300}$ of a second. This was obtained with a $\frac{6}{1000}$-inch lift of the valve, by slightly further loading the spring above normal and having the gap-limiting brass pins on the plunger about $\frac{1}{30}$ inch high. The pressure obtained is usually that occurring towards the end of the valve opening, and the reading recorded is usually much steadier than might be expected. For instance, in the case of a compressor, when the pressure was altering at the rate of $\frac{1}{2}$ lb. per degree, the shake on the gauge pointer was less than $\frac{1}{10}$ lb., although the valve must actually have been open during four degrees. A lift of $\frac{6}{1000}$ inch gives the same accuracy as $\frac{1}{64}$ inch, and only delays the steady reading by a few revolutions.

Mr. Bonn raises the question of speed. When more experience has been gained, there is little doubt that accurate readings will be obtained at fairly high speeds. At present I can only claim that the detector will give, if not exact data, at least more accurate data, at higher speeds, than are otherwise obtainable.

Mr. Brown points out the necessity for perfect tightness of the valve. As the valve is closed for a much longer period than it is open, there is time for back leak to occur at high-pressure points. In certain cases a very slight leak is permissible, but for low open-scale readings in a high-pressure cylinder the tightness should be perfect. As Mr. Brown indicates, any leak is easily found by testing for, and is not difficult to rectify. The valve will keep tight on a compressor indefinitely, but on a combustion cylinder particles of hard grit occasionally settle on the face. The apparent variation in lifting power referred to may have been due to cyclic speed variation of the engine. If the resistance is set so that the valve just lifts, a slight rise of speed may make the time of contact too short for lifting to take place. The work done by

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Mr. Norman Young.

Dr. T. W. F. Brown on combustion should be of the greatest moment to all who are interested in internal-combustion engines.

Mr. Austin indicates the way to higher speed, and suggests a less economical coil. The problem of coils is rather involved. The coil must be worked very cool in order that the timing will not gradually alter, due to increase of resistance. In the case of a contactor switch, the number of times of operation may be 20 or so per minute, while the coil here may act a thousand times. The higher the speed, the greater is the work done in the coil, and the greater the heat generated. The points to attend to in attaining high speed are low inertia, quick rise in current, low voltage at the lifting point, quick break, small lift of valve, only fractional reduction of air-gap with lift, and a greater spring pressure than is actually required to hold the valve shut against pressure. The breaking of the current at a voltage below 40 has been found more satisfactory for quick breaking than the introduction of a condenser.

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SOME NOTES ON DECK SUPPORTS.

By W. Henderson Carslaw, B.Sc.,
Member of the Institution.

24th January, 1928.

The intensity of competition in the shipbuilding world compels all concerned in the design of ships to scrutinise every detail, in order that each may be satisfied that every legitimate method of reducing weight has been considered, and that there is economic justification for all material included in the structure. The following notes on various types of deck support have been prepared in the hope that they may throw some light upon one item in this scrutiny.

The pure cargo and the pure passenger carrier present two distinct aspects of the question; the important factors of cost and weight are common to both, but conditions which affect the handling of cargo usually dominate the first.

In so far as the common factors of weight and cost are concerned, it is often regarded as an established principle that the fewer the number of parts the cheaper it is to build a structure; but this statement requires qualification when proper elaboration of design results, as it usually does, in a saving of weight, and is contradicted if it results, as it may, in such a reduction in scantlings that the material may be worked into the structure at a cheaper rate per finished ton. These possibilities indicate that the subject is worthy of serious consideration on all occasions and in all parts of ship design. In considering deck support from this point of view, it is fairly obvious that its potentialities are likely to become greater as ships get bigger, and a change from, say, one row to three rows of pillars makes more appreciable the weight effect of

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alterations in the sizes of beams and supports. Although the classification society is not directly concerned with this aspect of the problem, provided the arrangement is structurally efficient, it may not be out of place to suggest that, if the cheapest arrangement involves more weight and a consequent loss to the owner of paying deadweight, there are conditions where the builder is at least justified in giving the owner an opportunity of deciding between cost and weight. The variation in hull weight due to an elaboration in the method of pillaring may not be enormous, but in large vessels the figures are sufficiently impressive, even when account is taken of the fact that practical considerations may have prevented the adoption of the optimum arrangement.

Ease of cargo handling is a matter which obviously depends as much on the type of cargo carried as upon the arrangement of pillars. In the bulk oil carrier the main structure may be designed without giving more than a passing thought to obstructions in the cargo spaces, while at the other end of the scale—the cargo carrier for service on the Great Lakes—all pillar support may have to be eliminated, even at the expense of increased hull weight, in order to permit of the use of cargo grabs and steam shovels. In what is probably the most important type and that of which the most common examples are afloat, the general cargo carrier, the arrangements are usually a compromise between the ideas of owner, builder, and classification society as to the most satisfactory way to meet conflicting conditions of service. Generalisation on the merits and demerits of any system or combination of systems is impossible, but it is suggested that fuller consideration and discussion of the deck supports at an early stage of design and before the material is ordered, might, in many cases, lead to a saving in weight and a gain in clear hold space.

A series of estimates of the steel hull weight for vessels of varying size has been made in order to obtain some definite information on the weight effect of variation in the method of deck support of an ordinary cargo carrier. The ships considered were of average draught, and had the minimum free-

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board permissible by the 1906 Regulations, with $\frac{6}{10}$ of their length covered by erections. The scantlings were in accordance with the rules of the British Corporation Register, and the principal particulars are given in Table I.

TABLE I.

PARTICULARS OF SHIPS FOR WHICH HULL WEIGHT ESTIMATES WERE MADE.

Length, B.P.	200′	400′	500′
Breadth, mld.	34′	54′	64′
Depth, mld. to Upper Deck	16′ 6″	30′ 11″	38′ 11″
Draught, mld. Summer	15′	25′	30′
Freeboard coefficient	·78	·78	·78
Erections (Three-Island or Well Decker)	$\frac{6}{10}$	$\frac{6}{10}$	$\frac{6}{10}$
Sheer, mean at ends	45″	75″	90″
'Tween Deck Height	7′	7′ 6″	7′ 9″
Width of Hatchways	13·6′	21·6′	25·6′
Girder Span with Wide-Spaced Pillars	20′	30′	35′
No. of Decks	1	1 and 2	1 and 2
No. of Rows of Pillars	1, 2, 3	1,2, 3—1, 2, 3	1, 2, 3—1, 2, 3

The results of the calculations are given in Table II, and have been expressed in the form of percentages, the ship with one row of close-spaced ordinary stanchions being taken as the standard in each case.

At 200 feet length, the type and arrangement of the pillars have no important effect on the weight, and the simplest as well as the cheapest structure is the one-row ship with ordinary stanchions.

When provision for a centre-line grain division is required and permanent grain bulkheads are not fitted, close-spaced stanchions are adopted almost naturally, but in certain cases

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it has been found an advantage to use wide-spaced pillars, even for grain divisions, if they are not too far apart.

It may be pointed out that, so far as rolled sections are concerned, although the bending-moment on, and required section modulus of, beams and frames vary as the square of the span, their weight per foot run may be adjusted to increase approximately in direct proportion to the span, provided the most efficient section is employed in each case.

Table II.

Effect of Variation in Method of Deck Support on Steel Hull Weight of Cargo Vessels.

Length of Ship.	Number of Decks.	Type of Support.	Arrangement of Pillars.		
			1 Row.	2 Row.	3 Row.
			Per Cent.	Per Cent.	Per Cent.
200′	1	Close-spaced.	100	101·4	101·1
		Wide- „ (20′).	98·9	98·9	98·6
400′	1	Close-spaced.	100	99·8	99·3
		Wide- „ (30′).	100	99·7	98·4
500′	1	Close-spaced.	100	100·2	99·0
		Wide- „ (35′).	99·7	99·1	98·3
400′	2	Close-spaced.	100	98·3	96·6
		Wide- „ (30′).	100·6	99·8	97·9
500′	2	Close-spaced.	100	98·2	96·8
		Wide- „ (35′).	100·4	99·4	97·9

The figures for the 400-foot ship show that in the larger type of vessel there is a definite tendency towards weight reduction as the number of rows of supports is increased, and that this tendency becomes more marked when a second deck is fitted. It will be noted that, in the two decker, close-spaced stanchions are rather lighter than wide-spaced stanchions and

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girders. This is probably a consequence of being compelled to use uneconomical girders in the 'tween decks where their depth is artificially limited by the necessity for providing head-room.

In the case of the 500-foot ships, which may be regarded as representing the limit of present-day practice for cargo carriers, a considerable saving in weight is obtainable in cases where two or three row support is practicable, a saving which may represent an increase in paying draught of as much as two inches.

In considering the arrangement of pillaring to be employed in any particular case, the number of rows in a cargo ship is usually determined by the custom and requirements of the trade in which the vessel is most often engaged, but the weight effect of the large girder spans which are now common is not always fully appreciated. The modern tendency to increase the length not only of hatchways, which may be a necessity, but also of the interval between the pillars, is a factor which may cause a serious addition to the hull weight. Taking the 400-foot two decker with two rows of pillars as a typical example, it was found that, as compared with spans limited to 20 feet, the effect of increasing their length to 25 and 30 feet was to increase the hull weight by about $\frac{3}{4}$ and $1\frac{3}{4}$ per cent. respectively. This indicates the price which may have to be paid for a gain in clear hold space, for it should be remembered that, in practice, the girder spans vary in length in each hold, that the greater the length the greater the objection usually made to the depth of girder, and the greater the practical difficulty in reducing the weight and size of the shorter spans in just proportion.

It is interesting to note that, in a recent paper on "Girders in Ships"* by Mr. Foster King, figures were given which confirm the results shown above. Mr. Foster King's comparative weights are given only for the stiffening members themselves, and do not include the remainder of the structure, but they clearly indicate the feasibility of designing multiple

* Trans. North East Coast Inst. of Engineers and Shipbuilders, vol. xli, p. 31.

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member structures which are definitely lighter than those in which the number of components is a minimum, if the economic advantage of deep girders and stiffeners is fully realised by the designer.

In the arrangement of the supports of a passenger liner, a different set of conditions has to be met. Obstruction in the holds does not bulk largely in the picture, as the principal cargo usually consists of stores, baggage, and mails, and, even in the "mixed" type of passenger vessel, any inconvenience due to increase in the number of rows of pillars is outweighed by the increased head-room afforded by the reduced depth of beams in the 'tween decks, and by the fact that the supports can often be embodied in the cabin bulkheads. A few years ago considerable difficulty was experienced in obtaining adequate support for the decks of passenger spaces, but there is now evidence of a growing idea that perhaps, after all, unbroken vistas are monotonous, and that skilfully camouflaged strength members in the public rooms may add to, rather than detract from, artistic effect. The method of arranging the supports in a large passenger vessel which has satisfactorily withstood the test of service conditions is that which was first put forward by Mr. Foster King in his paper "On Large Deck Houses,"* and is now firmly established as a sound basis for design. The essential feature of his arrangement is the provision of definite and efficient support to the main hull and its superstructures from tank top to house top, by extending the watertight and other bulkheads upwards in the form of fire-resisting bulkheads and partial bulkheads, and providing adequate intermediate support for the deck girders, casings, etc. Effective girder design in way of the public rooms on the upper levels does not present much difficulty nowadays, in view of the large 'tween deck heights now adopted. Adequate support must be provided at the extremities of the houses by means of webs, diaphragms, and pillars, in order to transmit the loads between the upper and lower portions of the hull structure, and it is essential that arrangements

* Trans. Inst. of Naval Architects, vol. lv, part I (1913), p. 148.

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should be made for continuity of support, right down to the tank top. Some difficulty is usually encountered in obtaining the most economic proportions for long girders in passenger ships, but fortunately there are many areas where the balance may be restored by using the most economical spacing of pillars.

In the general design of deck supports, as has been already emphasised, there are many points of conflict between practical requirements and economical design. Reference has been made to the restraining influence of head-room in 'tween decks, but even in the holds the depths of girder are often restricted by such seemingly irrelevant factors as stevedores' charges. When girders are very shallow in relation to their span, experience has clearly shown the necessity for employing scantlings which, on paper, show a substantial margin of strength and weight over those of a normally proportioned girder, as a provision against unreasonable deflection. It hardly appears necessary to point out that the rivet attachment at the ends of such girders should also be greater than that required for the corresponding girder of normal depth.

When considering girders from the point of view of weight and cost, it should not be overlooked that a comparatively thin plate will serve for the vertical web of a deck girder, because its principal function is to maintain the distance between the bottom flange of the girder and the deck, so that, when conditions of heavy load and long span have to be met, a combination of relatively thin web plate and heavy face bar should weigh less—if it costs more—than a flanged girder plate of the same depth and equal strength.

Where solid pillars are employed as wide-spaced supports, the head and heel attachments require attention. It may be stated definitely that the riveting suitable for the same size of stanchion, when close-spaced, is not sufficient to withstand the more severe conditions imposed upon the rivets by girders of considerable span.

Another point to emphasise is best illustrated by our common knowledge that a civil engineer, designing a foundation for a

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column carrying 300 tons (as has sometimes to be done in a ship), would evolve a structure very much more substantial than the intercostals with which classification societies reinforce ⅜-inch floor plates. Broadly speaking, it is safe to say that shipbuilders do not always consider the absolute mass which is concentrated on points of the hull structure. It is also scarcely possible to over-emphasise the need for pillaring additional to that required to carry the deck weights at all points subjected to severe stresses, such as at breaks of superstructures, in the machinery space, and at the after end. Only by such means can vibration be avoided, and the structure rendered satisfactory in service.

The type of pillar to be fitted in cargo spaces deserves consideration before adoption. From the point of view of hold capacity, the "four angle," "two bulb angle and plate," and "double channel" may show a slight gain, but less damage is caused to cargo by solid or tubular pillars. Built tubes are, however, not suitable for spaces which may be filled with water, owing to the impossibility of making them tight, with the result that corrosion—not easily detected—takes place, and the pillar may unexpectedly fail under load. In deep tanks, where the pillar acts as a tie rather than a strut, stability may become a secondary consideration, and primary attention should be directed to the ability of the proposed arrangements to withstand pure tension. The deck girders in deep tanks should be carefully designed in order to meet dynamic effects, and it will be found that a girder of strength only sufficient to take the static load requires reinforcement.

The sum of the evidence points to the adoption of as many lines of deck support as may be convenient, and the use of girders as deep as other considerations admit. It also draws attention to the desirability of considering the spacing of pillars from the point of view of balancing the economic values of weight, cost, and obstruction, in the light of the advantage to the whole structure of adequate and *stiff* support. An endeavour has been made to show that, while it may not always be convenient nor practicable to reduce hull weight by the

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design of the supports, a little consideration may sometimes produce a more efficient structure without increase in weight.

It only remains, in conclusion, to express deep appreciation of the assistance received from my colleagues on the technical staff of the British Corporation Register in the preparation of these notes.

Discussion.

Mr. A. P. Cole, R.C.N.C. (Member): This is a very valuable paper on an extremely difficult subject, and it is interesting to see that the classification societies and merchant shipbuilders are considering reduction of weight, even in small quantities. This matter has been of considerable importance in Admiralty ships in recent years, and I can assure Mr. Carslaw that although the reductions in weight which he indicates in Table II may not seem very large, it is surprising how these relatively small savings total up to quite an appreciable amount.

There are one or two points in the paper on which I should like further information. It would be of great help in understanding his figures if Mr. Carslaw would state definitely what conditions or limiting factors he has assumed in making the calculations for Table II. He has throughout the paper indicated certain limitations. For example, he says that uneconomical girders have to be used in the 'tween decks where their depth is limited by the necessity of providing headroom. On page 389 there is reference to a further limitation on account of stevedores' charges, and also a reference to the heavier scantlings required to prevent unreasonable deflection.

On page 386, Mr. Carslaw makes the definite statement ". . . so far as rolled sections are concerned, although the bending-moment on, and required section modulus of, beams and frames vary as the square of the span, their weight per foot run may be adjusted to increase approximately in direct proportion to the span, provided the most efficient section is employed in each case." This is hardly borne out by the British Corporation tables, which appear to indicate that

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Mr. A. P. Cole, R.C.N.C.

the weights of rolled sections per foot run increase at a less rate than the span. For girders, of course, the weight increases at a greater rate than the span, due to the fact that the web plate has to be of a definite thickness. On the whole, therefore, if British Corporation scantlings are used as stated in one part of the paper, the statement referred to above does not appear to be substantiated, and Table II would require modification. I have no doubt that the figures are calculated correctly, but perhaps it is worthy of note that whereas for a 200-foot ship with one row of pillars there is an increase in weight when proceeding to two rows, for a 400-foot ship under similar conditions there is a decrease, and for a 500-foot ship again an increase. A similar argument applies when considering whether to adopt close-spaced or wide-spaced pillars; for some cases there is a decrease in weight or no change, in others an increase.

I understand that the percentages given in Table II are based on the steel hull weights. If that is so, it would be of advantage to have the actual saving in weight in each of the five quoted cases, instead of percentages.

Reference is made on page 384 to an optimum arrangement for deck supports. What is the optimum arrangement, and how do the calculations in Table II compare with it? Has Mr. Carslaw considered deep transverse beams, say 20 feet apart, with continuous longitudinal girders and shallow intercostal intermediate transverse beams? Does this bear any resemblance to his optimum arrangement? With reference to the design of girders, Mr. Carslaw states that "a combination of relatively thin web plate and heavy face bar should weigh less—if it costs more—than a flanged girder plate of the same depth and equal strength." What does he mean by relatively thin web plate? What thickness is it? Relatively thin web plates, considered from the Admiralty standpoint, are not entirely successful, and it is much better to adopt a thicker plate lightened above the continuous bar.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member of Council): Perhaps Mr. Carslaw will tell us why generalisation

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Mr. W. H. Riddlesworth, M.Sc., M.Eng.

on the merits and demerits of any system of deck supports is impossible. I do not see it. The value of Table II would, I think, be increased if Mr. Carslaw would add the percentage of total steel weight that is affected by these changes. It would be interesting to know whether we are dealing with 10 per cent. of the total weight and making changes thereon, or whether the percentage is greater or less

On page 389, I find an opportunity of reintroducing the subject of my recent paper. Mr. Carslaw says "When girders are very shallow in relation to their span, experience has clearly shown the necessity for employing scantlings which, on paper, show a substantial margin of strength and weight over those of a normally proportioned girder, as a provision against unreasonable deflection." I suggest that this is clearly a case where it would be advisable to define the form of failure as deflection, and, in addition, specify the maximum stress allowable, which may be the elastic limit or may be something else, but I think the designs ought to be examined from a deflection point of view, and not entirely or mainly from a stress point of view. On the same page Mr. Carslaw says, "Where solid pillars are employed as wide-spaced supports, the head and heel attachments require attention." I presume they always do. "It may be stated definitely that the riveting suitable for the same size of stanchion, when close-spaced, is not sufficient to withstand the more severe conditions imposed upon the rivets by girders of considerable span." Now, stanchions of the same size ought to be able to carry the same load, and to carry the same load they should have the same riveting attachment; if they do not require the same riveting attachment, they are too large in the one case and too small in the other.

Mr. Carslaw says, on page 390, "Built tubes are, however, not suitable for spaces which may be filled with water, owing to the impossibility of making them tight." I venture to differ from him. I think built tubes can quite readily be made water-tight. It is a very simple matter to roll a plate into a tubular form, to weld the seam, and caulk

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the angle rings at the top and bottom so that they are quite water-tight.

Mr. J. L. ADAM (Member of Council): Mr. Carslaw's paper is obviously intended for the particular consideration of shipowners and shipbuilders, and it would be much more profitable to have their views, as mine must, of necessity, be derived from much the same information as forms the basis of the paper. I would like, however, to emphasise some of the points that Mr. Carslaw has brought up, and, I think, rightly, especially his remarks regarding the spacing of pillars and the growing tendency to increase this spacing.

The average hatchway in a cargo ship is approximately 30 feet in length, but it is gradually increasing, until to-day 40-foot hatchways are quite common, and the 50-foot hatchway is an actuality. As Mr. Carslaw shows, the difference in weight between girders of 50-feet span and those of 30 feet is not merely the difference between 50 and 30, and it seems to me that shipowners might very well reflect as to whether the few occasions on which they need that 50-foot span justifies them in the extra expense of introducing it. I would like to compliment Mr. Carslaw on a paper which obviously has entailed a great deal of work on a subject of particular importance, and one, moreover, which, so far as I know, has never been discussed by a technical society.

Mr. G. J. INNES (Associate): This subject is exceedingly interesting, and has been treated by Mr. Carslaw in a manner understandable to the non-technical person. Mr. Adam referred to the size of the holds, and the tendency to increase these continually. Mr. Carslaw has taken a 60 per cent. superstructure in a 400-foot ship. That would leave something like 160 feet for the two well decks if she were of the three-island type; that is to say, 80 feet for each well. Now if in each of these wells are placed a 50-foot hatch and a 20-foot hatch, only 10 feet is left for winch beds, etc., which is obviously quite inadequate. The point I wish to make is

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Mr. G. J. Innes.

that, in a vessel of this type, any hatch over 30 feet long becomes a freak hatch if she is built for standard trading. If hatches in excess of 30 feet long are introduced, she ceases to be a standard vessel, and becomes one built for a special purpose.

Locomotive carrying has in recent years influenced the length of hatches, but this again is a special purpose, and if a general purpose vessel is adapted to meet more or less adequately the particular purpose of locomotive carrying, then those special requirements are provided at the efficiency of the vessel's general requirements. For the sake of argument, let it be assumed that a general trader carries locomotives, say, one voyage in ten. Additional earnings on carrying the locomotives must of necessity compensate for the loss in earning capacity over ten voyages (through decreased available deadweight) to justify the large hatches on economic grounds.

Mr. Cole referred to the strength of the diaphragm plates. The principal strain a plate of that sort has to withstand in a cargo space is getting struck by clumsy pieces of cargo during loading and unloading, and I think this very practical factor is a limiting one in the weight of these webs.

The depth of girders in 'tween decks is an important point, as the obstruction they offer relative to deck height is more noticeable in the 'tween decks. With the common arrangement of two rows of pillaring, the line of girders in the average cargo boat is usually on the line of the hatchways, and just at the point where those responsible for loading the steamer desire the maximum head-room, there it is reduced. Mr. Riddlesworth has referred to pillaring in deep tanks. For many reasons there is a very definite limiting factor to the length of deep tanks. These compartments are usually short; they require heavy longitudinal wash plates which provide ample strength, and I should be pleased if Mr. Carslaw could give instances of deep tanks where pillars have been introduced. He makes a reference to stevedores' charges in relation to pillaring. If he had said stevedores' language, it would perhaps have been more appropriate.

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Mr. W. W. Marriner.

Mr. W. W. MARRINER (Vice-President): May I say a word from the passenger's point of view? Once when I was crossing the Atlantic, the passengers were very much dis-

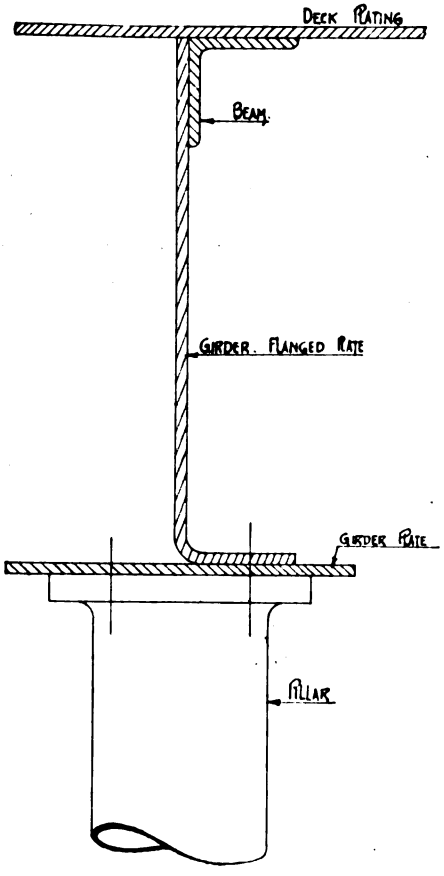

FIG. 1.

turbed by discordant noises in the ship during bad weather. One afternoon the captain and I took a walk round to see if it was possible to discover the reason for some of the squeaks, which were most elusive. We detected the cause

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of one noise; it was due to the method of taking the weight of the structure at the top of a pillar, and Fig. 1 illustrates how this was done. It will be seen that the vertical member of the girder just above the pillar was flanged at one end, and consequently it did not take the weight directly in line with the plate. Every time the ship rolled, the flanged plate bent a little at the radius and emitted a squeak. It appeared that it would have been much better to secure the vertical plate of the girder at both the top and the bottom by angle irons.

On another occasion, when crossing the Atlantic in a large steamer, a great many passengers were attending Divine Service on a Sunday morning, during which nobody is expected to move about or change seats unless there is a very good reason for doing so. The service was held in a large saloon, which had evidently been designed, as Mr. Carslaw says, at a time when considerable difficulty was experienced with large passenger spaces, owing to shipowners requiring them to be free from pillars. During the service the chief engineer thought it an appropriate time to go into the stokehold to see if he could improve the combustion of the oil fuel. He evidently made some experiments with the air pressure, and reduced it until the furnace burning the oil fuel began to pulsate. Unfortunately for us, the period of the pulsation synchronised with the period of vibration of the large saloon floor, and those who were sitting in the centre of the saloon, where the movement was quite considerable, would have given anything for some supporting pillars, and many of the passengers were in need of the benediction.

With reference to the remarks made by Mr. Innes about the size of hatches, I would like to suggest to him that to-day everybody wants things made bigger and bigger. If we make a big boiler, our cousins across the Atlantic immediately make one double the size, and the tendency is for our friends to want everything dispatched to them in the finished state. They do not like products sent out to be riveted up and finished abroad. Owing to the increase in size, a great

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Mr. W. W. Marriner.
difficulty is found in persuading shippers to take some of our productions, and I would ask Mr. Innes, who is a shipowner, to consider whether it would not be worth while stipulating for his hatches to be as large as possible, so as to help us and at the same time secure this kind of freight.

Mr. T. R. Thomas, B.Sc. (Member): Mr. Carslaw is to be congratulated on the production of this most interesting paper, which brings to our notice the variations in the weight of various types of deck support in, if I may say so, a somewhat unusual manner. He deserves our thanks for his courage in presenting the results of his investigations without obscuring the issue by describing the investigations themselves. It is interesting to see the rate of change of the reduction in weight of vessels having one-, two-, and three-row support. Evidently the slight increase recorded in Table II for the 500-foot vessel, is due to the fact that the increase in weight of the additional row of pillars has more than counterbalanced the saving effected by the reduction in the scantlings of the beams. This leads me to make a request for further information which Mr. Carslaw may have obtained during his investigations. Can he give an indication of the variation in weight with variation of spacing of the pillars? It would appear that the advantage to be obtained by increasing the pillar spacing is very marked until the associated girders become inefficient due to the depth limitation.

I suggest that Mr. Carslaw has not made quite clear the fundamental difference between his investigations and those made by Mr. Foster King. Any reduction in the weight which is obtained by an increase in the number of supports is not to be confused with the reduction obtained by the subdivision of the panels dealt with by Mr. Foster King, but it is, nevertheless, possible that the economies effected in both cases may be combined. In the case of a single-row ship having a pillar span not more than the half-beam of the ship, would it not be possible to subdivide the deck by means of transverse girders supporting in turn subsidiary longitudinal girders?

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Mr. T. R. Thomas, B.Sc.

From a casual consideration of this suggestion, it would appear that in small vessels a system of deck support might be evolved which would show considerable economy in weight.

In the case of the 500-foot vessel, has Mr. Carslaw used the same stress basis for the close-spaced and wide-spaced arrangements? I submit that he should give consideration to the possibility that, in a vessel of this size having a single deck, close-spaced pillars provide the more effective structure.

A CORRESPONDENT: I have been keenly interested in this subject, and am sure the tables giving the effect on total hull weight of vessels by the various methods of deck supports will be of the greatest interest to shipbuilders and shipowners.

I agree entirely with Mr. Carslaw's remarks in the case of cargo steamers. The case of passenger ships, however, presents greater difficulties. I have in mind the type of vessel, say 500 feet in length, designed to carry meat or fruit in the holds and 'tween decks, with two 'tween decks above fitted out for passengers in large two-berth rooms, extending from the corridor bulkhead to the ship's side, and having large public rooms on the deck above. In the holds and 'tween decks the minimum depth of girder is essential, necessitating a system of close-spaced pillars, say, from 6 to 10 feet apart, and according to Mr. Carslaw's research it would appear that the three-row system should be adopted, as the saving in weight is approximately 1·4 per cent. over the two-row system. Assuming that three rows of pillars is decided upon, extreme difficulty will be found in arranging this system of pillars. Mr. Carslaw states that the pillars can be embodied in the cabin bulkheads, but very often there is considerable difficulty in retaining the pillars immediately over each other, as the spacing of cabin bulkheads can very seldom be arranged immediately over each other in the different 'tween decks, which is the object aimed at in all pillar and girder designs. For this reason the shipbuilder is very often compelled to resort

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A Correspondent.

to two rows in these passenger spaces, making the casings form a row of pillars. Should the vessel in question have a hold which extends about 21 or 27 feet abaft the passenger bridge front bulkhead, it can be readily seen that if the two-row system is adopted in passenger spaces, and the three-row system in the holds and 'tween decks to suit fruit or meat, these systems must be efficiently scarphed past each other, and this involves fitting five rows of pillars in the holds in way of the scarph. This, of course, is very objectionable from a shipowner's point of view, and the builder is compelled to resort to the heavier system of two rows of close-spaced pillars throughout the vessel.

With reference to pillars and girders in public rooms, I am afraid there are still too many shipowners who allow themselves to be influenced by decorators, in the desire to dispense with pillars in these rooms. It invariably happens in these cases that excessive vibration is felt in this vicinity, which gives great annoyance to passengers and officers alike. In this connection, a vessel built some years ago had public rooms fitted over each other. In the upper room the decorators insisted on two pillars instead of one being fitted immediately over the pillar below as designed by the builders. The new pillars were about six feet out of line with the pillar below, and the builders increased the girders to take the double load. On the first two voyages considerable vibration was experienced, and on the recommendation of the builders, the shipowners cut out the two pillars and fitted the single pillar as originally designed. It was found that the vibration was practically eliminated.

I only offer these remarks to assist in the discussion, as I am sure many members of the Institution will have encountered similar cases which have required special consideration by builders and shipowners alike. I consider that the question of pillars and girders does not, in many cases, receive the attention due to it from ship constructors, and I hope the discussion will be the means of drawing more attention to this important part of a vessel's structure.

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Mr. John Anderson.

Mr. JOHN ANDERSON (Member of Council): While I do not agree with all Mr. Carslaw's conclusions, I think that his effort will cause all ship designers to look into this problem of the cost and weight of girders much more closely than they have done in the past. It is rather interesting to see in Table II the comparison between ordinary close-spaced stanchions and the wide-spaced pillars which are so generally adopted to-day, and it may be instructive to those who have not gone into the historical part of this subject to know that it was only in 1898 that wide-spaced pillars were actually introduced for ship work. At that time the late Mr. H. B. Wortley, of Liverpool, was bold enough to space them as much as 37 feet 6 inches apart, the girder he adopted being a complete box.

It is unfortunate that Mr. Carslaw does not say more of the process which enabled him to arrive at some of the very fine comparative results shown in Table II. I became so interested in these figures that I arranged to have a series of calculations made. First of all, I tried a two-row girder system, each row running in line with the hatch coaming, which, in this case, formed a girder. Then I considered a three-row system with the girders placed equidistant, and weights were made out for 35-foot and 23-foot spans. The results showed that the three-row system for one hold in a 500-foot ship was about six tons heavier, as made up from the scantlings obtainable by Lloyd's rules for girders of quite normal depth. In neither case was the depth of girder clamped. I mention this difference because, in Table II, Mr. Carslaw shows a difference of roughly 1·7 per cent. of the hull weight in favour of three rows, as compared with two rows; 1·7 per cent. saving means something like 45 tons in a 400-foot ship with two decks, and perhaps 70 tons in a 500-foot ship. This difference, of course, is probably due to what has been included in the comparison, and I should like Mr. Carslaw to explain a little more fully how he arrived at these differences.

Dr. A. M. ROBB (Member): Mr. Carslaw has produced a paper of the type that is not open to criticism—a record of

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Dr. A. M. Robb.

carefully collected and unquestionable facts. My one regret is that the paper was not available about two years ago, when I was interested in the design of some very broad single-deck ships in which it had been stipulated that the holds should be entirely free from obstructions other than the centre-line grain bulkheads. Incidentally, although the ships are nominally single-deckers the fact that they are of the long-bridge type really seems to put them into the worst category as regards the weight penalty for the elimination of pillars. Not having any data for ships of such breadth with only centre-line support to the beams, it was necessary in the first estimates merely to guess the extent of the weight penalty. But, and here arises a very minor criticism on a valuable paper, the owners flatly refused to consider the question of the additional weight involved in their request for clear holds; their trade necessitated clear holds, and that was the end of the matter. And so, in effect, there was no question of "economic justification"; clearness of holds cannot be reduced to economic terms.

Mr. Carslaw: The discussion to which this paper has given rise proves that the subject has not been devoid of interest, and it is hoped that it may be possible to explain some of the points about which doubt has been expressed.

In carrying out the series of weight estimates, an endeavour was made to approximate to the conditions of practice by limiting the depth of girders in the 'tween decks to the extent which is usual, in order to afford adequate head-room, while the depth of those in the holds was restrained to 20½ inches on account of the limitation imposed by stevedores' charges. These restrictions rendered it impracticable to employ the most economical girder scantlings in every case, and explain the relative increase in weight where spans are lengthened. So far as the rolled material for frames and beams is concerned, the lightest and deepest section was used in every case, although it was realised that this may not always be possible in a design where cubic capacity is the vital factor. It was

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Mr. W. Henderson Carslaw, B.Sc.

suggested in the discussion that the tables of the British Corporation Register do not bear out the statement made on page 386 regarding the rate of increase of weight with span, but analysis of the rules of that society will show that it does hold good for rolled sections, because the designer is left free to use the best available scantling.

In order that the figures given might be strictly comparable, the same stress basis and method of calculation were employed throughout the series. It must be ascribed to the influence of university training that the percentages shown in Table II are given, with probably false accuracy, to one place of decimals. This appears to have somewhat misled several of those who contributed to the discussion, and the suggestion is proffered that if the figures are corrected to the nearest half per cent., they will probably represent the limit of accuracy in this type of calculation, if statements by builders of merchant ships as to the degree of approximation of actual to estimated steel weights be accepted. It must be frankly admitted that, in making the estimates, time did not permit of the detailed consideration which the calculations would have received at the Admiralty. It is also a matter of regret to me that I had no opportunity of making estimates for the interesting system of support suggested by two contributors to the discussion, which certainly has possibilities where freedom from obstructions in the hold is essential, and which has, in fact, been adopted in some cases as being the lightest practicable arrangement.

It may be suggested that "clearness of holds" can be "reduced to economic terms" if, as is usually the case, one arrangement which achieves that end is definitely superior to others. Relative superiority can, however, only be ascertained, as was emphasised in the paper, by investigation *prior* to construction—a course which is often well worth while.

The discrepancy between the weights quoted by one speaker and those given in the paper is apparently due to the difference in the scantlings used rather than to any vital difference in the method of calculation.

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Mr. W. Henderson Carslaw, B.Sc.

The effect of increase of span has, perhaps, not been sufficiently emphasised in the paper, but the figures given on page 387 were intended to be indicative of the movement towards increased weight. The important fact is, that the limits of acceptable depth of girder are reached at spans much shorter than those which are common to-day, so that each successive increase in span renders the girders less efficient per unit of area, with consequent increase in weight.

Although in many general trades any hatchway of more than 30 feet length may still be considered a freak, yet it is not so very long ago that 20 feet was a very long hatchway. The growing desire for suitable provision for the export of boilers, locomotives, and large machinery will probably induce a further increase in length, and 40 feet may soon become a common requirement in cargo carriers.

The allusion to the optimum arrangement of supports gave rise to several queries, probably because "generalisation" was incorrectly used. At the present stage of development in the science of naval architecture, this is a subject on which "particularisation" of the best arrangement is definitely impossible.

The increase of scantlings in shallow girders, referred to on page 389, is necessarily made, as was suggested by one speaker, in order to reduce deflection by increasing the moment of inertia of the cross section.

In the course of the discussion, interesting examples of bad design were given which serve to point the moral of the paper, and to bring home to owners and builders the importance of the problem which has been submitted for consideration.

Mention of the historical side of the subject recalls that, when Mr. Wortley took the then extraordinary step of supporting the decks by two lines of girders, each carried on a single pillar at the middle of the length of a main hold, he received the active co-operation and support of the British Corporation Register. It is only now, 30 years later, that such arrangements are becoming a commonplace of design.

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In conclusion, I would express my gratitude and thanks to all those who, by their contributions to the discussion, have added to the common stock of knowledge, and have rendered my paper worthy of a place in the Transactions of the Institution.

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THE BUELL SYSTEM OF PULVERISED COAL FIRING.

By G. E. K. Blythe, Ph.D., B.Sc.,
Member of the Institution.

7th February, 1928.

Economic Use of Low-Grade Fuel.

The incentives to fuel economy, that is to say, to rendering available in the cheapest and most efficient way everything of value present in fuel, whether in the form of coal or coke, oil or gas, are stronger to-day in this country than they have ever been in the past, or at any previous stage in its industrial and economic history.

We, therefore, find advocates of innumerable systems, which range from oil and gas burning to low-temperature carbonisation, making clamorous appeals on behalf of individual proprietary processes, to such an extent as to bewilder the plain man, who may find little or no information of a definite character to guide him in selecting a system suited to his own special requirements.

Prominent among the systems of fuel economy in vogue at the present time is the use of pulverised solid fuel, in contradistinction to oil-burning systems in which liquid fuel is sprayed into the furnace. It has the advantage that very low-grade coal can be thoroughly and economically consumed, an advantage of considerable value, seeing that such fuels are far cheaper to begin with, and that their supply is plentiful.

It is also an economically sound proposition when using high-grade coal, owing to the very complete combustion which the fine particles undergo, and the ease with which the rate of combustion, and, therefore, the temperature, can be controlled.

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If pulverised coal did not attain entire success during its early history, such lack of success cannot be attributed to the general principle of burning coal in pulverised form, as this is basically sound, but rather to the lack of comprehensive knowledge of the science of combustion and the unsuitability of the pulverising plant at that period.

The science of pulverised-coal firing, however, has now proceeded far beyond the experimental stage, and, given the fulfilment of certain fundamental conditions, it can be said that it is as satisfactory and reliable from all standpoints as any of the other methods now in use for power raising and metallurgical heating.

What is Pulverised Coal?

The answer is, any carbonaceous fuel, be it high-grade anthracite or bituminous coal, slack and smalls, dust and pit, waste, lignites, peats and brown coals (passed through a preliminary crusher if necessary), the moisture content of which has been reduced to 5 per cent., according to the nature of the fuel to be pulverised, and which subsequently has been ground to an extremely fine powder in special mills.

By this means a lump of coal, say a one-inch cube, exposes a surface of six square inches, but the same piece when pulverised into cubes having sides of $\frac{1}{1000}$ inch develops a total oxidisable surface area of 6,000 square inches. The finely divided particles are carried into the furnace in suspension by the air required for combustion, and a flame is obtained which somewhat resembles gas or oil firing, and can be controlled by adjustment of the mixture of air and fuel or its rate of discharge.

In the "Buell" system the control of the air is very exact, and most of the air for combustion meets with the coal dust as it is leaving the burner. Any system that relies, wholly or partly, on the conveying air only to supply oxygen for combustion is likely to be inefficient, for, in addition to the deficiency in volume, the fact that the particles of coal travel

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at the same rate as the particles of air, prohibits proper mixture of the two. In the Buell burner the air for combustion is supplied in three separate streams, two of them from the fan additional to the propelling air, and the third an induced flow from the stokehold. With such a burner, ignition and combustion of the coal particles take place instantaneously, a maximum flame temperature is developed, and there can be no loss of thermal value or unconsumed carbon under such conditions of combustion.

In the Buell system the type of pulveriser used depends on conditions of working and quantity of fuel required, since the Buell process depends for the excellent results obtained in practice upon the construction of the burner itself, and to this extent is independent of the kind of pulveriser employed. It works with the Kek pin mill, W.A.C. impact mill, and Fuller-Bonnot mill, because these have been specially designed for the purpose, and can be adjusted to grind coal so that 83 per cent. passes through a 200 mesh.

Buell Turbulent Burner.

The most rapid ignition and combustion possible is desired to obtain the highest furnace temperatures, and thus the highest efficiency. The small powdered-coal particle entering the furnace at the burner mouth is first of all heated up before combustion starts. This heating is by stages. First, any moisture in the coal must be vaporised. The drying process is endothermic or heat-absorbing; that is, the furnace walls surrounding the flame must furnish this heat to raise the temperature of the incoming coal particles and to start distillation, which is the next stage. While some of the radiant heat is furnished by the surrounding walls, the greater part comes from the flames of burning coal and gases.

This reverberatory action of the flame is highly important, particularly with low volatile coals. The distillation change starts at about 400 degrees F., and gases and volatile vapours are given off, forming smoke until combustion starts. The

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distillation process is also endothermic, unless the oxygen content of the coal is high. The entering coal particle, being a black body, readily absorbs radiant heat, and increases in temperature.

The primary air which accompanies the coal is a poor absorber of radiant heat, and may have increased in temperature only slightly, when the gases begin to distil. In fact, the air is heated largely by convection from the coal particles suspended in it, and which are absorbing radiant heat. The smoky gases from the coal contain carbon particles which continue to absorb radiant heat, thus increasing their temperature. Finally, the air-gas mixture reaches ignition temperature, and combustion of the gases commences.

The burning of the volatile matter produces water vapour and carbon dioxide, both of which will absorb and also give out a considerable amount of radiant energy. The combustion of the volatile matter may be considered a step-by-step process where the hydrogen first unites with oxygen, freeing the carbon in an atomised state, but highly heated by the burning hydrogen. Undoubtedly a certain amount of heat, resulting from the combustion of the hydrogen, is absorbed and dissipated as radiant heat by the free carbon particles, which are nearly pure black bodies, and which give luminosity to the flame. Experiments have shown that luminous flames with incandescent particles of carbon floating in them radiate more heat than non-luminous flames.

More radiant heat is emitted and may be absorbed from the flames of a pulverised-coal furnace than from those of an underfeed-stoker furnace, due to this large volume of flame of greater luminosity. Much of the secondary combustion in the flame with stokers is due to the carbon monoxide, which burns with a non-luminous flame, and, hence, has less radiating power. The rapidity with which the free carbon particles in the pulverised-coal furnace combine with oxygen depends very largely on the speed of mixing with heated air. This is true of the coke which now forms the remainder of the original coal particle. The speed of combustion of this coke

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and the consequent length of flame travel are dependent upon rapid mixing.

Unless the products of combustion of the volatile gases are swept away from the coke, it remains surrounded by inert gases. Oxygen cannot reach the particle until this gas envelope is removed further along the flame travel. The coke takes an interval of time to burn, and fresh supplies of oxygen must reach the coke throughout the whole combustion period. The extent of mixing necessary can be appreciated from the fact that the particle of coke must come into contact with many thousand times its own volume of air under furnace conditions, in order to burn completely.

Violent mixing is, therefore, an essential of rapid combustion and short flames. Turbulence of the mixture has been found desirable for rapid ignition in solid-injection oil engines, and turbulence in the furnace is also an essential factor in the burning of pulverised coal. The only burner capable of giving the required conditions of turbulent flow is the Buell burner. With this type of burner the area of the fuel cloud may be increased seven-and-a-half times before it leaves the outer mouth of the burner, and in this way two great advantages are secured:—*Firstly*, intimate mixture of air and fuel, and diminution of velocity; and, *secondly*, complete combustion within a few feet of the burner dependent upon the size employed.

It is well known that the efficiency of industrial furnaces is generally very low, and the importance of a systematic study of reheating, forge, annealing, and all classes of furnace, has of late repeatedly been urged, both in the interests of fuel conservation and industrial prosperity.

The conditions governing the efficient combustion of fuel are now well understood, and if proper control is effected the thermal loss in unburned products need not be considerable. The real problem in furnace work is the successful application of the heat generated to the purposes in hand. This involves an understanding of the fundamental physical principles underlying the mode of heat transfer from the hot gases flowing

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through a furnace to the charge, whether directly by radiation and convection, or indirectly by radiation from the heated walls and roof. The effective utilisation of the sensible heat of the flue gases for the preheating of the air for combustion is, of course, also a fundamental condition of high furnace efficiency.

The application of pulverised fuel to various forms of metallurgical heating has been the means of greatly increasing the efficiency of working.

The Buell System in Metallurgical Furnaces.

The salient points in the Buell system of pulverised-fuel firing as applied to metallurgical furnaces may be summed up as follows:—

1. The air control is absolute. In a practical test extending over three months, complete combustion was achieved with an excess oxygen supply never exceeding one per cent., with complete absence of CO in the chimney gases. The importance of a non-oxidising flame in the melting and refining of costly metals, and the annealing of case-hardened parts, or of articles the surfaces of which it is necessary to preserve free from oxide contamination, coupled with the actual fuel economy shown by the absence of CO in the test cited, are advantages the importance of which it is impossible to exaggerate.

2. The atomisation of the fuel, its intimate admixture with air (without any unnecessary excess), and the special design of the adjustable sleeve, nozzle, and deflector mechanism enable complete combustion to take place within five or six feet of the burner.

3. The flame is horizontal, and the velocity can be adjusted so that a long travel is not required for complete combustion. Moreover, not only can the air supply, shape, and length of the flame be adjusted to comply with the requirements, but its direction can be altered at will.

4. The temperature can be controlled with facility, and is uniform throughout the furnace. This is seldom, if ever, the case, even with the most skilled hand-firing. The flame

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emerging from the Buell dispersive burner may indeed be said to spread, tulip-wise, so as to fill uniformly the entire furnace space. There is no chance of uneven heating, and the risk of warping or distortion of articles undergoing annealing or other forms of heat treatment, is, therefore, entirely obviated.

5. The secondary air can be preheated, thus further increasing the efficiency.

6. The saving of fuel from the combined causes enumerated has been estimated as ranging from 26 to 50 per cent., depending on the type of furnace. Labour and time are also saved, apart from the great indirect economy arising from the non-oxidising nature of the flame and the consequent saving of waste and reduction losses in metals due to oxidation.

7. The use of pulverised fuel has often occasioned difficulties owing to the fierce nature of the flame resulting from what may be termed the intensive combustion of the pulverised-fuel particles. The control under which the Buell burner operates entirely obviates these objections, and avoids the heavy resulting wear and tear on furnace linings and refractories due to the scouring action and to unequal local heating. The ideal "soft" heat which can be obtained with the Buell system has been a revelation to many experienced metallurgists who require a well-controlled, penetrative, and uniform heat for many materials, and have had hitherto to depend upon highly skilled (and expensive) hand-firing methods to obtain the necessary conditions.

The Dust Difficulty.

It must be admitted that the dust troubles attendant upon the use of pulverised fuel have often been exaggerated. In power plants, the dust trouble does not operate in a well-designed plant, when reasonable care is exercised. Fig. 1 shows a flue-cleaning apparatus applied to a Lancashire boiler. It would be folly, however, either to deny, or to seek to minimise, the very real nature of the dust problem in metallurgy. Not only are molten metals subject to serious contamination, but, as

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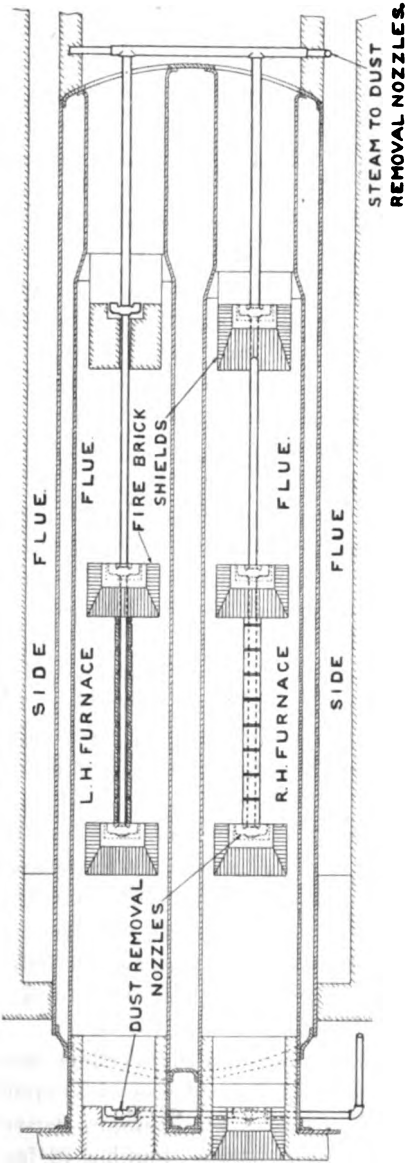

Fig. 1.—Sectional Plan through Furnace Flues.

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in the case of tin smelting, serious wastage may occur. There is always some loss from slagging, and the amount of metal lost with the slag is proportional to the amount of slag produced; the best practice cannot reduce losses from this cause to less than about two per cent. of the weight of the slag. Anything, therefore, likely to increase the volume of slag formed will seriously increase these losses in the same proportion, and in cases where a low-grade coal with high ash content, otherwise perfectly suitable for pulverised-fuel firing, is employed, the dust becomes a very serious and objectionable feature. The same remarks apply, *mutatis mutandis*, in the case of many other metals, and when, as in the case of nickel, cupro-nickel, and similar products, the oxidation trouble intervenes further to complicate matters, equally heavy loss and wastage may be encountered.

It is, in this connection, a highly significant fact that the Buell system has been adopted in the tin and other highly-priced ore industries, and is rapidly extending in this and in other countries. Fig. 2 shows a section of a reverberatory tin-smelting furnace which has been in constant operation for 2½ years.

Evidently the Buell system eliminates the dust trouble, and as this cannot be said of any other system of pulverised-fuel firing, it is of interest to inquire just how and why this most objectionable feature has been so successfully surmounted in the system under discussion.

In the first place, it is necessary to repeat that the perfect control of the air supply in the Buell system has enabled pulverised coal to be employed for the smelting of tin. Attempts have been made with other pulverised-fuel systems, but, even when the size of the combustion chamber was greatly enlarged, the various systems tried failed signally to give entire satisfaction.

What the other systems failed to effect was accomplished by the Buell system. At the works of Penpoll Tin Smelting Co., Ltd., Bootle (to take an example derived from actual British practice), a combustion chamber, 8 feet by 2 feet by

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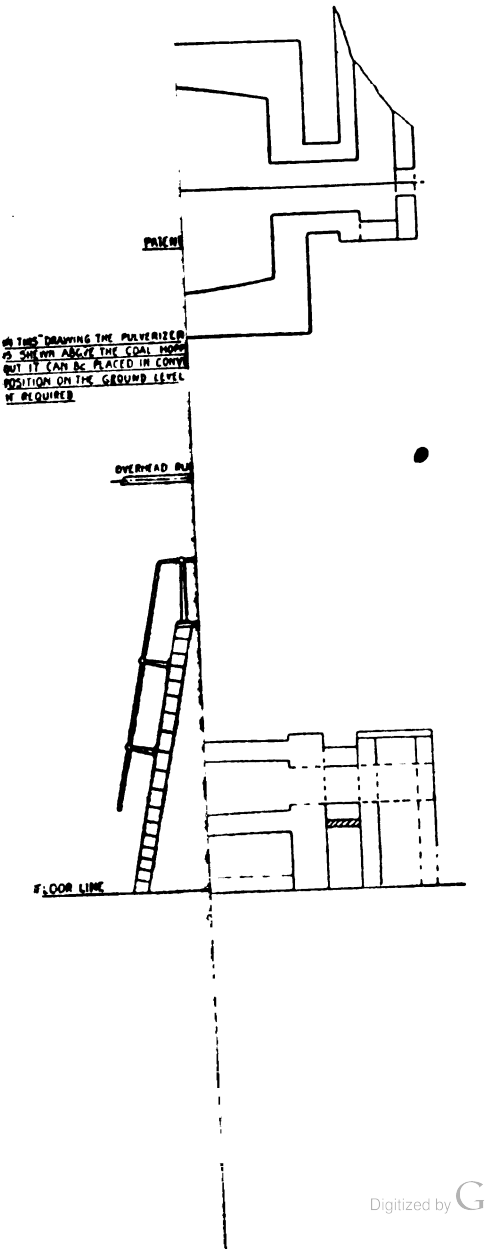

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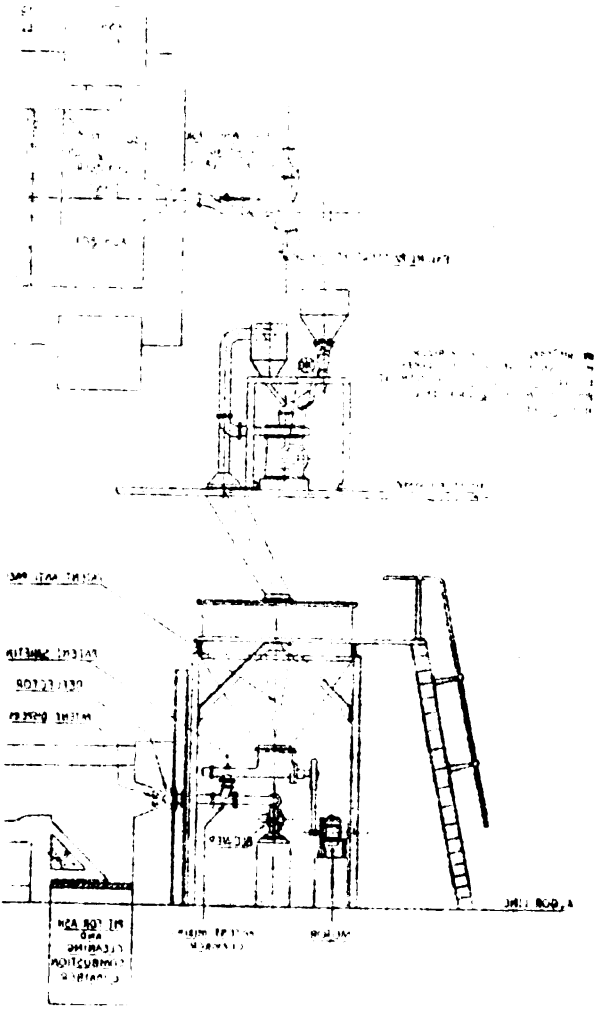

Fig. 2.—Recuperator, Tin-bridge

2½ feet, was employed. It had previously been used for hand firing. Without increasing its size, a Buell burner was installed, in such a manner as to point to the bridge wall, two feet distant. The furnace beyond the firebox was 20 feet in length. The working temperature of the furnace was 1,500 degrees C., and the furnace ran continuously for 18 months. In a communication to the Buell Combustion Co., Ltd., the

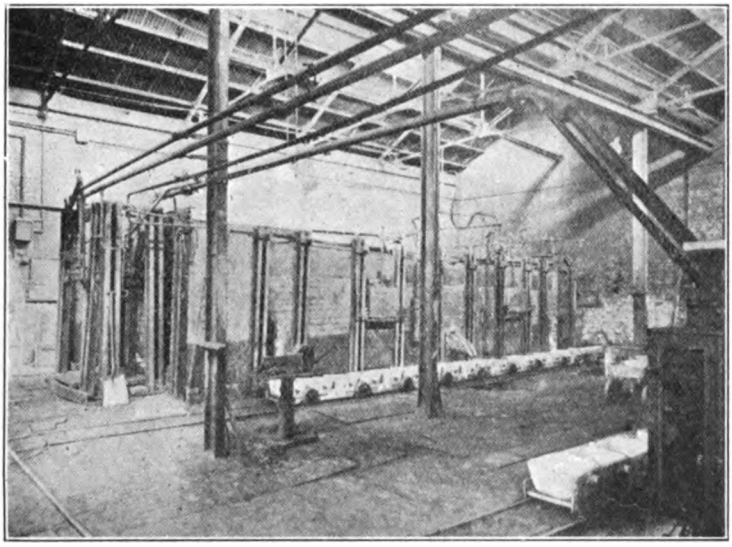

Fig. 3.—Cupro-Nickel Furnace at the Mond Works, Clydach, with Buell System Attachment.

Penpoll Co. state that they have had two Buell burners in constant use in their smelting and calcining plant, one since June, 1924, and the other since October, 1924, and in both instances the work done has been very satisfactory. Temperature control is simple and elastic, and fuel consumption shows a very material saving on all other methods tested, and, generally speaking, the burners have proved efficient and economical.

This indicates that the dust trouble has been circumvented, but it does not indicate exactly how it has been done. The

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clue is to be found in the reference to the bridge wall "two feet distant." The flame impinges on this wall, carrying with it the inevitable dust in fine particles. The temperature of these dust particles and of the bridge wall are such that the dust particles projected against it stick like flies to a fly paper, and the resulting viscous deposit, acting in the first instance

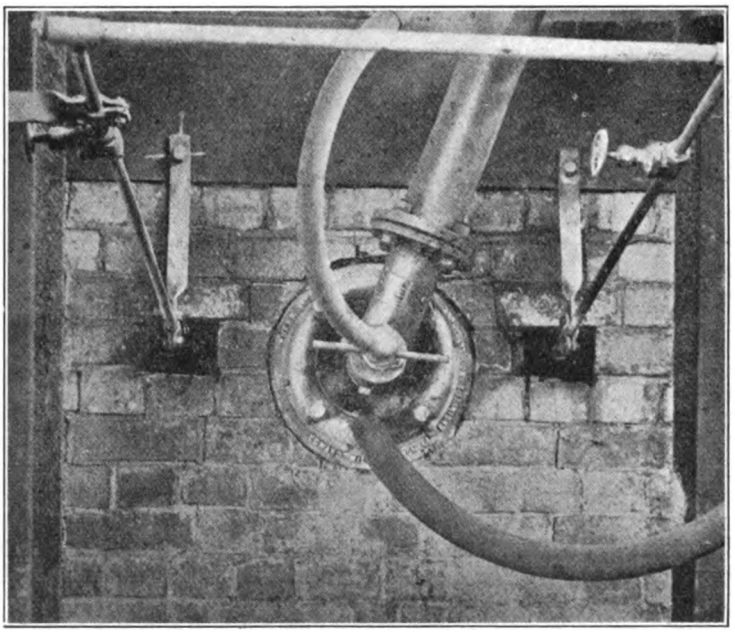

Fig. 4.—Buell Burner Housing.

as a coating, which protects the bridge bricks from the abrasive and scouring action of the dust blast, trickles innocuously into the well, or ash trough beneath, and is removed at intervals, without having done any harm to the costly contents of the furnace bath beyond. What happens, then, is admirable in its simplicity, and equally admirable in its results.

It is not, therefore, surprising to find that the Buell process is being adopted in other metal industries. The unhindered dust nuisance may cause trouble by altering the slag-metal

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or the lime-silica ratios on the slag. That, in the Buell system, this does not occur is shown by the fact that the Mond Nickel Co., whose high technical skill and attainments few would care to challenge, have adopted the system in their large cupro-nickel furnaces at their Clydach plant, South Wales.

Fig. 3 illustrates a furnace of this description, and Fig. 4 shows the Buell burner housing and attachments at the end of the furnace.

Examples Derived from Actual Recent Practice in Non-Ferrous Metallurgy.

In regard to the actual fuel economy effected by the use of this process, the following recent figures are illuminating:—

In a furnace running on tin slag, a charge requiring ten hours to work on hand firing involved the consumption of 37½ cwts. of coal. The introduction of the Buell system enabled the same furnace, working on a charge of the same weight and operating under otherwise identical conditions, to complete the charge in seven hours with a coal consumption of only 11½ cwts. The time saved thus amounted to more than one working day per week, while the fuel economy was some two-thirds of the former coal bill.

Two further instances may be given. A non-ferrous reverberatory furnace having a throughput capacity of nine tons of metal per 24 hours, consumed, under the original hand-firing conditions, four tons of coal. When the Buell system was installed, it was found that no less than 16 tons of metal could be dealt with in the same period, while the coal consumption was only three tons. Finally, a furnace in use by the United Water Softeners, Ltd., for the manufacture of their well-known speciality "boromite," which requires to be most carefully preserved from the slightest contamination with dust, and was, therefore, gas-fired, has been changed over to pulverised-coal firing on the Buell system. Not only has the dust question been solved to the entire satisfaction of the company, but the very substantial saving of £600 per annum

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has been effected in the company's fuel bill. In this connection, it may be pointed out how perfectly the Buell system adapts itself to emergencies. The burner can be changed over, in a few minutes, to burn either pulverised coal, gas, or oil. To do this, it is only necessary to remove the burner designed for one type of fuel and to replace it bodily by another.

Buell Burners.

1. Of the dispersive Buell burner and the non-dispersive Buell burner, the former is the more characteristic, and is

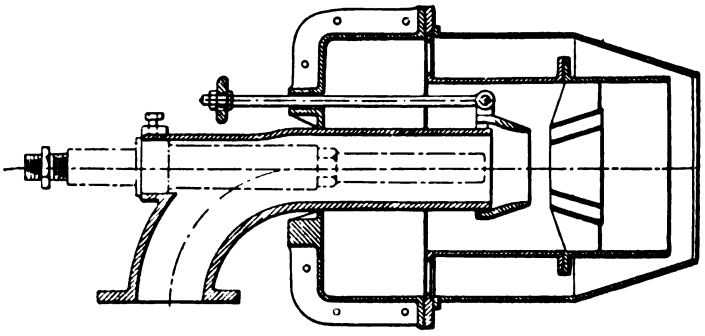

Fig. 5.—Buell Dispersive Burner arranged for Oil Firing.

illustrated in section in Figs. 5 and 6. The curved fuel-supply pipe *f* is prominent in both figures. The coal is discharged through an annular space round the internal primary-air inlet *a*, this space being greater or less according to the position of the hollow cone *b*, which forms the end of the inlet pipe. Outside the fuel inlet are two concentric casings *h* and *i*. The inner one *h* carries a pair of conical rings *c*, expanding from the direction of the jet, while the outer casing *i* terminates in a conical portion contracting against the direction of the jet. The external primary-air supply from the fan is introduced through the annular space between *h* and *i*, either from a continuous chamber *g*, or, more normally, through four pipes, connected by a common ring. The secondary air, induced by

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the injector action of the coal stream, enters through louvres at *j* into the space between the inlet pipe *f* and the casing *h*. These louvres are distinguishable in Fig. 4, as is also the ring for the external primary air with its flexible supply pipe from the fan. The flexible pipe shown in the upper half supplies the internal primary air. Sometimes the external primary-air pipes function as secondary air inlets, in which case the louvres are closed.

The working of the burner will be followed from Fig. 6. The internal primary-air inlet *a* is adjustable horizontally by

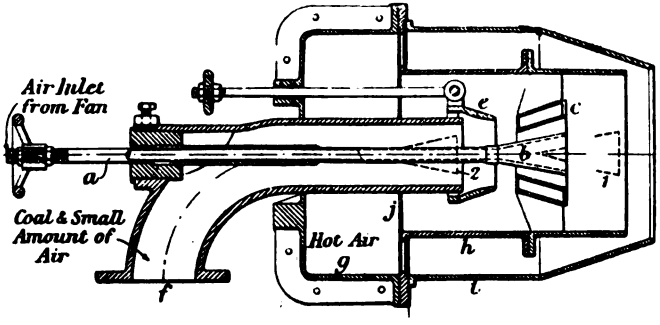

Fig. 6.—Buell Dispersive Burner arranged for Coal Firing.

a screw motion controlled by a hand-wheel. The hollow cone *b* is made with a solid central cone, so that the jet of air issuing from it is, like the coal stream, hollow. When the cone is in the extreme forward position 1, the jet of coal dust has been opened out only a little way by the internal primary-air jet, when it meets the converging stream of external primary air at the mouth of the casing *h*, the two streams striking one another at an acute angle. The result is a comparatively long flame carried between the two sheets of eddying air. When the cone *b* is drawn back to the extreme rearward position 2, the coal stream is opened out immediately it leaves the inlet pipe, to such an extent that it impinges on the edge of the casing *h*, striking in its course the rings *c*, which break it up

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and assist in mixing it with the air. At the outer edge of the casing *h*, the coal stream, which is then spread over seven-and-a-half times its original area, meets the external primary air at a less acute angle than in the former case, and the destruction of the velocity effected by the converging currents is more marked. There is, under these conditions, a region of combustion immediately outside the mouth of the burner, where a turbulent effect is very noticeable. The velocity of the coal and air jets being absorbed in creating this disturbance,

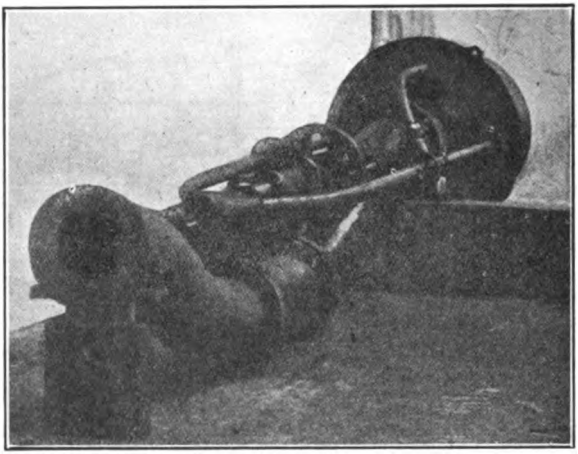

Fig. 7.—Buell Non-Disperaive Type Burner.

the resultant flame is short and of a bushy character, with practically perfect combustion. The shape of the flame can, obviously, be varied between the two limits by suitably adjusting the cone between positions 1 and 2. One important feature of the burner, which is shown in Fig. 6, has not yet been alluded to. This is the conical ring *e* over the end of the coal-inlet pipe. By means of this it is possible to change the flame from a strictly axial direction to one at a considerable angle to it, a feature which is very useful, in some cases, with industrial furnaces. The ring is pivoted in the middle, and can be tilted round this axis by the sliding rod shown, the fuel

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stream being diverted either upwards or downwards as required.

2. The non-dispersive burner, Fig. 7, has a long flame, suitable for such applications as cement kilns, etc. Internally, the cardinal difference between the two types is that in the non-dispersive type the casing *h*, Fig. 6, tapers inwards, and the rings *c* are omitted, while a sliding sleeve is fitted over the coal-inlet pipe, so that the position of its outlet end may be varied relatively to that of the tapered casing, and the width of the zone of junction of the secondary air with the coal supply can be controlled. The burner shown in Fig. 7, being for a large cement kiln, is considerably larger than the burner shown in Fig. 4, apart from the difference in type, but the distinctive details are recognisable in both. Behind the end of the coal-inlet pipe, in the foreground of Fig. 7, is a triple branch for air from the fan. The centre pipe of this branch runs through the burner to the end of the sliding sleeve above mentioned, which is, indeed, controlled through the movement of the pipe by the hand-wheel shown. The two side pipes run into the external primary-air space, each of them dividing on the way so as to provide the four air pipes previously mentioned. Each of these pipes is fitted with a stop valve for the purpose of regulating the volume and distribution of the external primary air, which is a very important point when the calorific value of the coals used varies from time to time. The corresponding valves in Fig. 4 are visible as small knobs on the external primary-air ring. Although combustion commences close to the burner in both cases, and is completed within a very short distance of it in the dispersive type, the casting of which it consists is not affected by the heat, owing to the three streams of air which pass through it when working.

Driers.

The necessity of drying the coal before pulverising has been often called into question, particularly by operators whose coal supply is normally of low moisture content. The facts are

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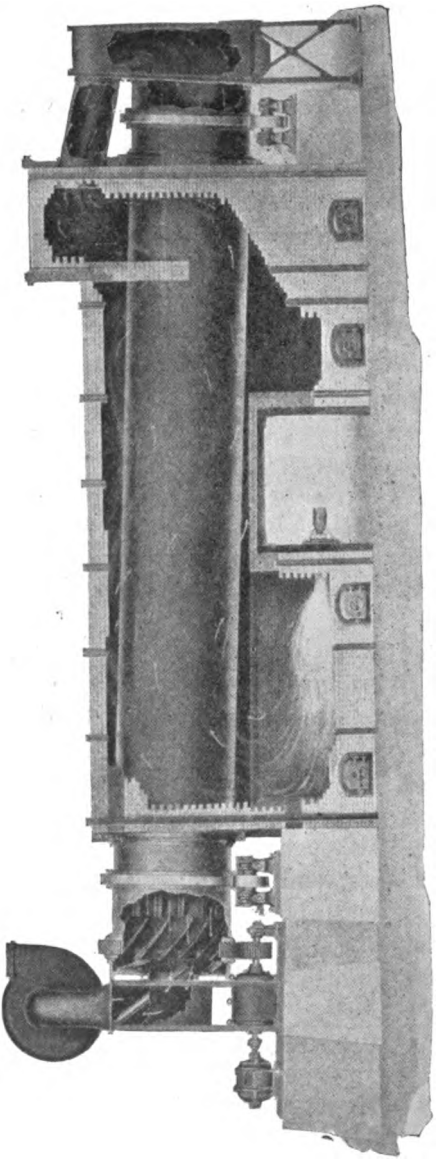

Fig. 8.—Indirect-Fired Rotary Drier; Pulverised-Coal Fired.

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inescapable, however, that drying the coal considerably increases the capacity and reduces the power consumption of the pulverisers, and makes its handling after pulverising a positive instead of a doubtful operation Damp pulverised material is one of the most refractory substances to handle, hanging up and blocking operations at every point possible, and its transportation is unreliable and a continuous annoyance. When dried, the fuel mixes and burns more readily in the furnace, and, as the moisture must be removed either before or after entering the furnace, the effect on fuel economy is almost negligible. Even when coal is very dry as normally received, there will be occasions when the weather will make drying essential, and the absence of proper drying equipment may cause interruptions that will prove to be far more costly than its provision would have been.

The presence of moisture in coal, like ash, must be regarded as a dead loss. It may be present as "inherent moisture," originally combined with the coal as mined, or "free moisture," introduced by adverse climatic conditions, washing processes, etc. Generally speaking, moisture reduces the available boiler efficiency more than an equivalent amount of well-burnt ash, and is, therefore, an expensive diluent which should be avoided as much as possible.

Two types of driers are available—the rotary, which has been standard for many years, and the vertical stationary type, of comparatively recent development. The former consists of a rotating shell, slightly inclined, and ribbed internally, through which the material passes by gravity in conjunction with the rotation of the drier. The hot gases usually pass around the outside of the shell before entering and flowing through it, and are in direct contact with the material, which is picked up by ribs and dropped across the path of the gases. This is known as the indirect-fired type of rotary drier, Fig. 8.

The vertical drier is a sectional box through which, in the usual arrangement, the coal flows by gravity on its way from the storage bin to the pulveriser, Fig. 9. Hot gases, under fan pressure or suction, pass through the interstices in the body of the

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material, and carry off the moisture. These gases are preferably taken from the boiler stack, in which case the term "waste-heat drier" is usually used. Steam-heated surfaces may also be incorporated in this drier to assist the evaporative action of the gases. The fact that the drier is stationary and occupies

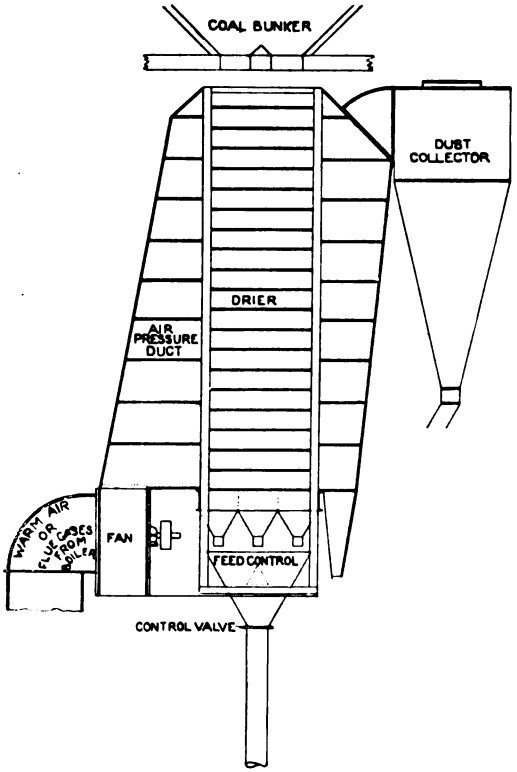

Fig. 9.—Randolph-Type Vertical Drier.

much less space than an equivalent rotary drier, not to mention its lower cost, makes it preferable under certain conditions.

Cyclones are essential for removing the dust in the discharged gases from a rotary drier, and are desirable with a vertical drier, particularly when the coal contains a consider-

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able proportion of fines. A large volume of comparatively low-temperature gases is generally desirable, and pyrometers or thermometers are used to permit proper control. In summer there may be times when the coal will be sufficiently dry before entering the drier. In that case the coal is passed through the drier as usual, but the hot gases are eliminated.

Broadly speaking, driers can be divided into four main classes:—

1. Driers designed so that the hot gases pass into the drier and come into direct contact with the coal. This practice is not recommended owing to the loss resulting from distillation of volatile constituents.
2. Driers designed so that the hot gases pass right through a central tube in the drier to the fan end and then return into contact with the coal.
3. Driers arranged so that a division of the hot gases takes place, a small portion finding its way into the drier in contact with the fuel, and the major portion heating the exterior of the drier shell before entering the drier.
4. Driers designed so that the furnace gases envelop the exterior of the drier shell, none passing into the drier until the temperature of the gases has been reduced to the safe point.

The terminal temperature of the coal as it leaves the drier should be not more than 250 degrees F., but latitude in this direction is governed by the nature of the coal, its ash, and its sulphur content. Apart from the attendant disadvantages in pulverising and conveying coal containing a high percentage of moisture, a direct heat loss is occasioned, due to the fact that the vapour formed is discharged to the atmosphere in a superheated condition. Each pound of water present in the coal will require roughly 140 B.Th.U's. to raise its temperature from that of the boiler house to 212 degrees F. It must then be supplied with 967 B.Th.U's. in order to convert the water at this temperature into steam at the same temperature, and this steam requires approximately 0·48 B.Th.U.

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for every degree through which it has to be raised to attain the temperature of the exit gases, or approximately 144 B.Th.U's. if the temperature of the exit is 512 degrees F. Thus, under the conditions assumed, every pound of water present in the coal requires a total of approximately 1,250 B.Th.U's. to allow its escape from the flue gases. If, then, a coal were to contain 10 per cent. of moisture, there would be a loss of approximately 125 B.Th.U's. per lb. of coal due to the effect of moisture alone.

Transporting Pulverised Coal.

When the coal has been pulverised, it must be transported to the point of use. A number of methods are available, the oldest being the spiral screw conveyor, operating in dust-tight steel troughs. This type of conveyor has many defects, however, as it is hard to keep clean, is dangerous unless given proper attention, and requires considerable power, overhead runways, and often numerous motor drives, since the distance over which one flight can be operated is limited.

Another conveying system consists of a pressure-tight tank, a source of compressed air, and a pipe line leading from the bottom of the tank to the destination. In operation the tank is nearly filled with pulverised coal, and sealed, and compressed air is then admitted above the coal, which forces the latter through the pipe line, discharging from the line into the furnace bins. In this system of coal transporting the disadvantages of the screw conveyor are eliminated, but other faults are discovered, these being that more labour is required in the operation, that the coal must be accepted and discharged in batches, and that the large volume of air required makes cyclone dust-collectors at the discharge end essential.

A third system, which is rapidly coming to the fore, consists of a pump having as an impeller a high-speed steel worm which takes the pulverised coal from a hopper and forces it into a pipe line. A small amount of compressed air is admitted into the material just beyond the discharge end of the worm,

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and the mixture of air and coal is forced through the pipe line to the destination. The worm is specially designed to compact the material as it approaches the discharge end of the pump, and this packing effect serves to prevent the return of compressed air through the worm to the hopper. As a result,

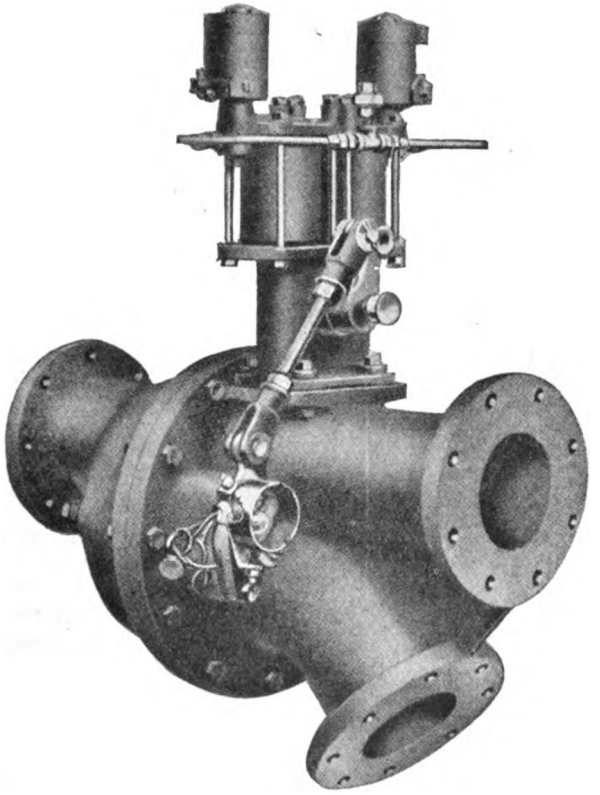

Fig. 10.—Electro-Pneumatic Distributing Valve.

the pump may be operated with an open hopper as long as an adequate supply of material is received by the hopper, which makes it ideal for transporting the coal from the mill spout to the furnace bin in one operation. The whole system is enclosed, so that there is no opportunity for dusting between

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the time the coal enters the mill and the time when it is delivered into the bin at the furnace. The system is also used to take pulverised coal from a storage bin and distribute it to various points as required. A complete electrical signalling system is used to indicate to the operator when the bin to which he is pumping has been filled, and to permit him to operate diverting valves to change the flow to other bins which are in need of coal. The operation is usually made automatic, in order to avoid any chance of overflow. This system of conveying has been used to elevate pulverised coal over a hundred feet, and to convey it distances of over a mile, the line pressure and the power required, which is comparatively low, depending upon elevation and distance. But little compressed air is required, and hence no cyclone is needed at the point of discharge from the pump line. The material as discharged is completely fluid, and levels off perfectly in the bin, retaining this condition for some time. In addition to the advantages of dustlessness, simplicity, and adaptability, the first cost of this system is low, and likewise the charges for labour and repairs, while repairs are easily and expeditiously made.

The Fuller-Kinyon System for Conveying Pulverised Coal.

The development of this system of conveyance makes it possible to transport pulverised fuel through a standard sized pipe-line with the ease, safety, and cleanliness of a fluid. The system consists of six essential elements:—

1. A power-driven pump.
2. A compressed-air supply.
3. A conduit or delivery line.
4. Electro-pneumatic distributing valves.
5. Bin material—level indicators.
6. A central signal and valve switching device.

The dried pulverised-coal is delivered by gravity to the pump hopper from a storage bin, weigh bin, or fed direct from the pulveriser mills. It is carried to the discharge end of the

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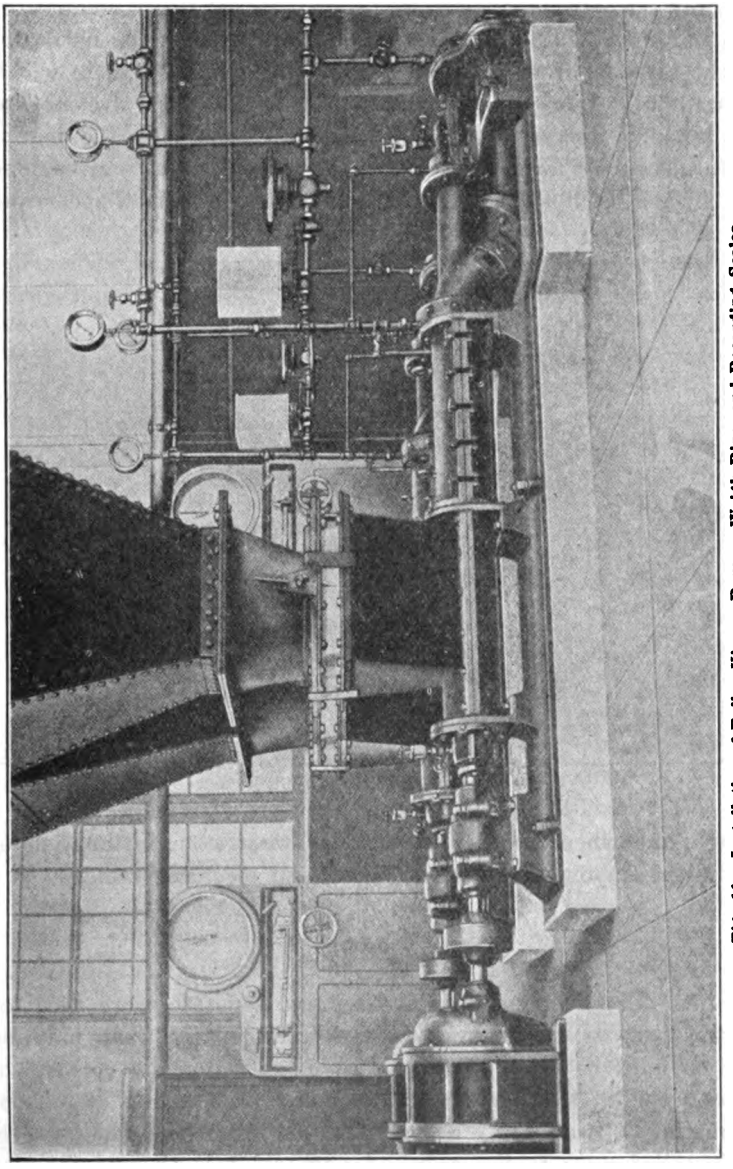

Fig. 11.—Installation of Fuller-Kinyon Pumps, Weigh Bins, and Recording Scales.

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screw, where the mass is aerated by a small amount of medium-pressure compressed air, thus changing the nature of the material from a compact mass into a semi-fluid, in which state it is transported through the conduit and valves to the individual service bins. An air line, by-passing the pump, furnishes air for actuating the electro-pneumatic valves, one of which is illustrated in Fig. 10, and is used also for clearing

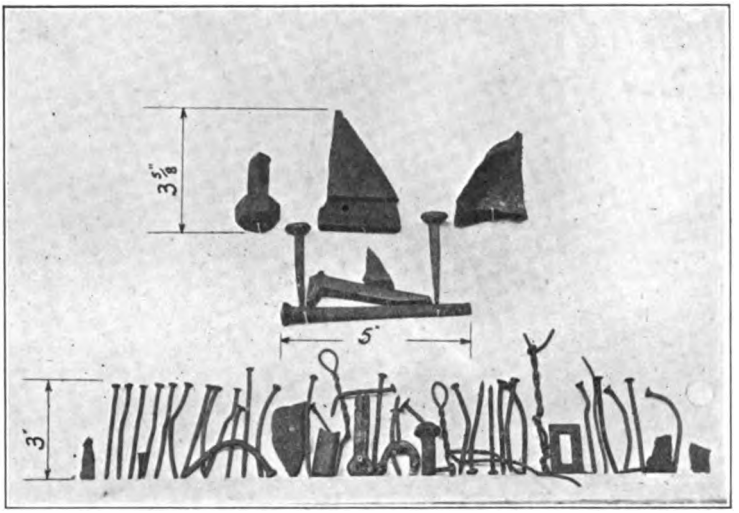

Fig. 12.

the line when desired. Fig. 11 illustrates an installation of Fuller-Kinyon pumps, weigh bins, and recording scales.

Magnetic Separators.

On all pulverising plants, magnetic separators are used for the purpose of removing any "tramp" iron that may be found in the coal. Tramp iron, Fig. 12, usually consists of iron spikes, splice plates, nuts, bolts, pick points, etc., from mining operations. Sometimes the magnetic separator is installed prior to the entry of raw coal into the storage bin,

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and, in addition, one is placed at a point before the coal enters the pulveriser. Both stator and rotary magnetic separators are used. The magnetic separator has also found an extending application with the increasing use of pulverised fuel, because the coal delivered to the power plant invariably contains a certain amount of tramp iron, which is exceedingly detrimental to pulverising machinery, and likely to cause considerable delay through a breakdown. This foreign material, which is magnetic, can be entirely eliminated by installing a magnetic separator pulley at a point preceding the crusher. When the material passes over the pulley, which is magnetised, the magnetic material is attracted and held firmly against the belt, and remains in contact with the belt until it leaves the magnetised zone, which is at some point beyond the under side of the magnetic pulley, and is delivered to suitable boxes by means of a chute, the coal continuing on its course.

The modern magnetic pulley for use in pulverised-fuel power plants consists of a number of steel discs keyed to a shaft, an electro-magnet winding being between alternate discs, Fig. 13. The magnetising coils are wound on steel bobbins, which are dowelled to the discs to prevent shifting. The coils are all connected in series, and terminal wires are brought through a hole in the centre of the shaft to a pair of collecting rings, fixed far enough beyond the edge of the pulley to permit the insertion of a bearing between the collector rings and the pulleys. The coils are impregnated with a moisture-repelling and insulating compound by the vacuum process, and the space surrounding them is filled with the same compound, poured in in the molten state during assembly. This ensures perfect protection from moisture, and since the compound is a better heat conductor than dead air, cooler operation of the pulley is secured.

In judging a magnetic separator pulley, it should be borne in mind that the dimensions and weight are not the only features to be considered. In fact, two separator pulleys of the same weight and dimensions could be made that would not be of the same efficiency. One may have less copper and

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more steel to secure cheaper construction, while the other, with an abundance of copper and not cheap, may be

Fig. 13.—Magnetic Separator.

spoiled by a lack of steel in the magnetic circuit. Magnetic pull varies as the square of the number of the lines of force per square inch of pole area, from which it may be seen that

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a small reduction, as from 100,000 lines per square inch to 90,000 lines per square inch, reduces the pull to 81 per cent. Too much steel in the poles reduces the number of lines of force per square inch just as too little copper does. The windings, if placed near the shaft instead of near the outside of the pulley, will require much less copper, but the efficiency will be reduced on account of excessive leakage.

The magnetising of the pulley is accomplished by passing direct current through windings in the interior of the pulley. The current sets up a magnetic flux, which passes through the belt and attracts any iron or steel in the coal. Pulleys of large diameter will in every case give better results than those of small diameter from the standpoint of magnetic separation, and will reduce wear and tear on the belt. Assuming the belt speed to be the same in both cases, it is obvious that the rate at which the direction of motion of a piece of iron or steel is changed will be lower on a large diameter pulley than on a small one; consequently, with the same intensity of magnetisation the separation accomplished by a large pulley will be more perfect than that by a small one. From the standpoint of belt life, the desirability of using a large diameter pulley is universally recognised. The pulley diameter must be large enough to give the required traction and to suit the thickness of the belt. Good practice allows three inches diameter per ply. Small diameter pulleys, however, are much lower in first cost, and where a short belt is installed their use is permissible. Where conveyor flights are long, and especially where the magnetic pulley is a driving pulley for the conveyor belt system, it is frequently economical to use a large diameter narrow-faced pulley, because of the saving effected in the cost of a narrow belt. These separator pulleys can often be used to replace the existing head sheave where a belt conveyor is being used, and in such cases it may be imperative to maintain the dimensions of the replaced pulley. Since a small diameter pulley is unsuitable for driving long or steep conveyor flights, it will sometimes be cheaper to install a separator pulley unit, say, about three feet long,

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on to which the main conveyor discharges. A similar arrangement can also be used where the material to be separated is being discharged from a chute.

Direct current is required to energise the pulley when in operation. Only a small amount of current is required, the average for sizes in greatest use being but a few amperes. Standard pulleys can be connected to any 110 or 220-volt direct-

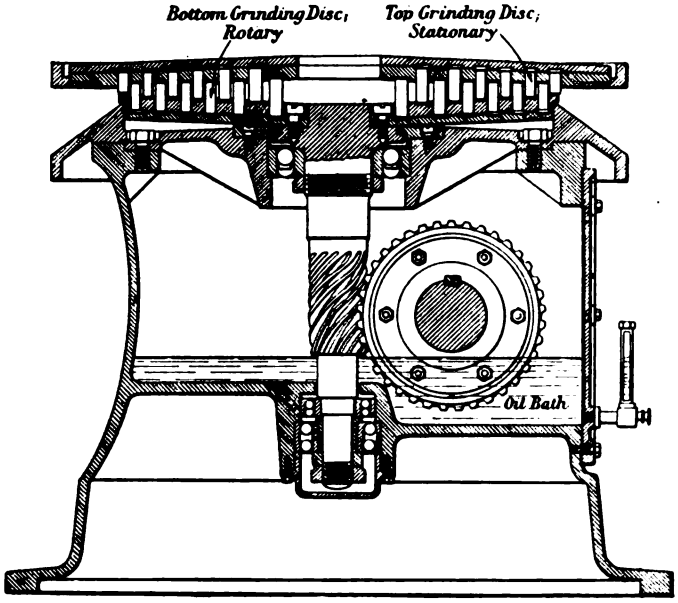

Fig. 14.—Details of Kek Mill.

current system, though pulleys are made for use on 500-volt direct-current circuits. The best working speed is 120 feet per minute belt speed.

Kek Mill.

Fig. 14 gives a cross-section of this mill, which is used for the pulverisation of many other materials besides coal. A 30 h.p. motor, running at 950 r.p.m., is employed for driving

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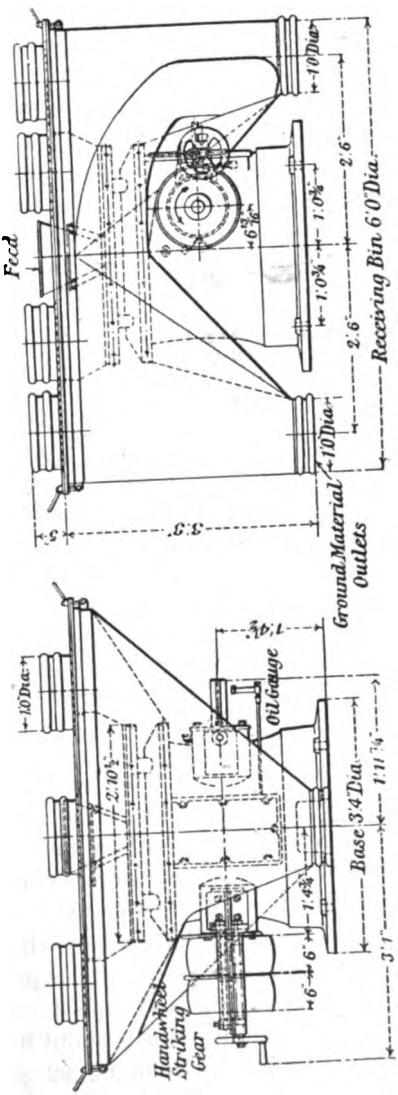

Figs. 15 and 16.

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this mill, being direct coupled to the horizontal driving shaft by means of a centrifugal clutch coupling. The drive is transmitted to the bottom disc, or rotor, through a worm and worm wheel running in an oil bath. The worm is cut in the vertical steel spindle, which is also provided with a flange at the top for holding the rotating disc. Both the horizontal driving shaft and the vertical spindle are fitted with double hollow-race ball bearings. A seal under the bottom disc prevents any ground material finding its way into the bearings or the oil bath. The bottom grinding disc rotates, and consists

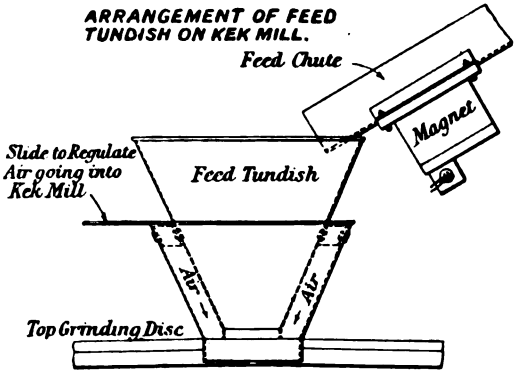

Fig. 17.

of a dished steel disc with a cover plate underneath which holds the teeth in place. The top disc is stationary, and is dished in the opposite way to the bottom one, so that the vertical distance between the two becomes less from the centre to the periphery. The pitch of the teeth is also decreased in this direction, though not necessarily their size, this depending upon the precise nature of the material to be ground. The teeth are of hard steel. With the shaft speed stated above, namely, 590 r.p.m., the bottom disc makes about 3,500 r.p.m., and will reduce coal to a fineness enabling 92 per cent. to pass through a 200-mesh sieve. The size of coal fed into the centre should not exceed that of a cube of two-inch side.

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The pulverised fuel is thrown off the rim of the bottom grinding disc on to the conical casting just below it, to which is attached the chute leading to the receiving chamber. Figs. 15 to 18 show a Kek mill coupled to a receiving bin six feet in diameter. The top of this bin is formed by a ring flanged in the centre, the flange being fastened to the top grinding disc, the outer portion carrying six branches for the dust-catching bags. The method of regulating the entry of air to

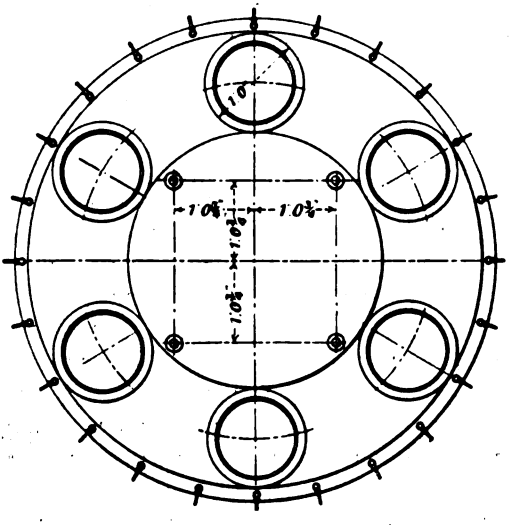

Fig. 18.

the mill is shown in Fig. 17. The lower portion of the bin consists of two funnels somewhat resembling irregular oblique cones. The inner surfaces of these are fixed to the conical casting under the bottom grinding disc, and meet at the centre, as shown in Fig. 16. The arch resulting from this construction is necessary to clear the driving gear of the mill, which in this case is shown as fast and loose pulleys, with a hand-wheel belt-striking device to ensure a slow start to the disc.

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Description of the W.A.C. Pulveriser.

A special feature of the W.A.C. mill is that the pulverising is done in two operations by rotating discs of varying diameter, which act in separate chambers of corresponding size. These discs are mounted on a horizontal steel shaft, and are housed in a pressure-tight cast-iron casing, thus avoiding loss or inconvenience due to dust.

The revolving and stationary discs are fitted with specially hardened steel abutment pins, between the surfaces of which the pulverising action is progressively carried out. The successful results obtained are due to the progressive spacing of the concentric rows of these abutment pins on the rotating and stationary surfaces, which ensures that, as the size of the particles diminishes, they are still subjected to the same shattering effects in all stages of the process.

The large volume of air generated by the action of the rotating discs and abutment pins is sufficient to carry over the finely divided particles into collecting bins and separators. The air current may also be utilised to propel finely powdered fuel direct into the boiler furnaces or storage bins, as desired, without any auxiliary air supply being necessary. The degree of fineness can be controlled within limits by regulating the rate of feed of material and the speed of rotation of the mill. If extreme fineness is desired, specially constructed sets of rotating and stationary plates and abutment pins are supplied, which are interchangeable with plants of the standard two-stage type. For still further degrees of fine grinding, special mills are designed having three or more stages.

An entirely enclosed circuit for the feeding and discharge of materials to and from the mills is arranged, thereby avoiding contamination of the atmosphere or wastage of materials. Mechanical feed gear can be supplied with all sizes of mill, the design depending upon the nature of the material to be dealt with.

In the W.A.C. mill all parts subject to wear can be easily replaced at a moderate cost. Double-track ball bearings

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are fitted to rotating parts, which are lubricated by grease, and are sealed from any contact with the materials being fed to or delivered from the mill. Using the standard type of two-stage mill, most materials under the chemical-minerals-cereals group can be reduced to fine powder in one continuous operation, without the aid of screens, fans, or perforated plates.

The Rema Ring Mill and Vacuum Systems.

The Rema mill consists of a free-running grinding ring, made of manganese or other very hard steel, inside which three specially hard roller crushers revolve. The top crusher is mounted on the driving shaft, and forms the driver. In working, the three crushers are pressed towards the inside of the grinding ring, and the material is ground as it passes between the three crushers and the ring. The bearings for the two free crushers are supported by springs only, and the openings for their shaft ends are arranged to permit of free movement in all directions. Leather gussets close the apertures around the crusher shafts. The arrangement of ring and roller crushers enables the grinding to be efficiently maintained until the ring and crushers are so worn as to require replacement. Minimum wear and low power consumption are attained, due to the simplicity of design and the slow speed at which the mills run. In the largest size the crushers revolve at 100 r.p.m., and the ring at 40 r.p.m. The bearings, being located outside the mill casing at each end of the shafts carrying the crushers, are not subject to the rapid wear associated with the mills employing crushing rolls, having bearings located internally. No oiling or lubricating cups are fitted, as heavy roller type bearings are used which only require filling up with grease at infrequent intervals.

The Rema vacuum system is embodied when a finely ground product is required, and consists of a high efficiency fan working in conjunction with an air sifter. The fan provides the air circulation necessary for lifting the raw material from the feeding device into the mill, for lifting the ground material from the

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mill outlet into the sifter, and for conveying the finely ground material from the sifter to whatever collecting device is used.

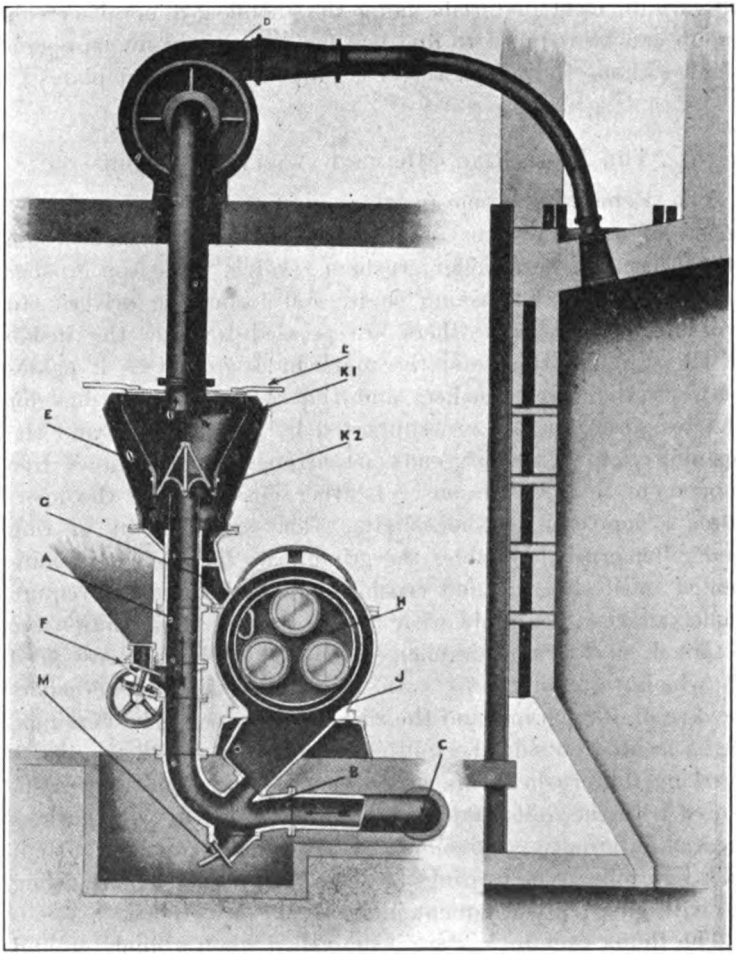

Fig. 19.

A diagrammatic arrangement of the Rema ring mill and vacuum system is shown in Fig. 19, the operation of con-

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veying, grinding, and separation being carried out in the following manner:—

The pipe A may be left open at its end B to the atmosphere, or alternatively coupled up with a source of hot air (represented by C) if the material requires drying. A current of air is induced by the high efficiency fan D, which is placed in the layout of the system after the pulverising mill and sifter. The air current passes up the pipe A into the space E between the inner and outer cones of the sifter, after which it is admitted to the inner cone, *via* openings K1, arranged round the upper part of the inner cone. From the centre of the inner cone a pipe is taken to the inlet of the fan D, the outlet of the fan being connected by means of piping direct to the burner in the case of powdered-fuel systems adopting direct firing. If the powdered material is required to be stored in bins or collected into sacks, casks, or other receptacles, the fan outlet is connected to a cyclone separator, and the system can then be arranged so that the air is returned from the cyclone separator to the pipe A by suitable piping, and the powdered material delivered to suitable receptacles. The air current induced by the fan D tends to create a vacuum in the mill and the sifter, and thus prevents the escape of dust.

Feeding Arrangement.

The feeding of the material to be ground is through the device F, Fig. 19, the mechanism being arranged so that the rate of feed may be quickly adjusted if necessary, the feed being constant at any particular setting. The material is caught up by air and lifted up the pipe A, and at the entrance to the lower part of the sifter the deflecting cone K2 tends to deliver the material into the chutes G, and since the velocity of the air current is reduced, due to the increased area of the sifter, only fine particles of material are carried through to the inner cone. The larger pieces fall down the chutes G, and are fed in at each side of the mill H, thereby ensuring even distribution across the inner face of the grinding ring, which results

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in minimum wear on the ring. The rollers pulverise the material which passes out of the mill outlet J into the pipe A, where it is entrained in the air current, and again carried along, together with the raw material being fed into the pipe A, to the sifter, where the larger pieces are delivered to the mill, and the finer particles carried up the space E between the inner and outer cone. At the entrance to the inner cone a series of adjustable vanes are fitted to the openings K1, which impart a centrifugal action to the dust particles entrained in the air current, and the final separation is completed in the inner cone, only the very fine dust being carried out of the system by the fan D. The coarser particles fall down the inside of the inner cone partly by centrifugal action and partly due to gravity, to be automatically returned to the chutes G, *via* discharging flaps, for regrinding in the mill.

The degree of fineness is regulated by the setting of the handle L, which adjusts the vanes at the entrance to the inner cone, thus controlling the centrifugal separating action of the air current inside the shifter. There are no revolving parts inside the shifter, and the regulating handle L is set to give the required degree of fineness; no further attention is necessary.

Material which is too heavy to be lifted by the air current falls down to the lower part of the pipe A, where it is easily removed by opening the trap M. Foreign materials, whether magnetic or non-magnetic, are thus prevented from entering the mill, although no damage would result if any metal were to find its way into the mill.

The vacuum system may be fitted to the beater type, pin or disintegrator type, or other enclosed mills, if desired, but these types of mill, however, are not recommended, as the cost of maintenance is much higher than when a ring mill is used. Fig. 20 shows the grinding armature being lifted out of the mill housing. It will be noticed that no complicated parts have to be dismantled or adjustments upset when it becomes necessary to replace the ring and roller crushers due to legitimate wear.

The ring mill, the inlet and outlet pipes, and the shifter

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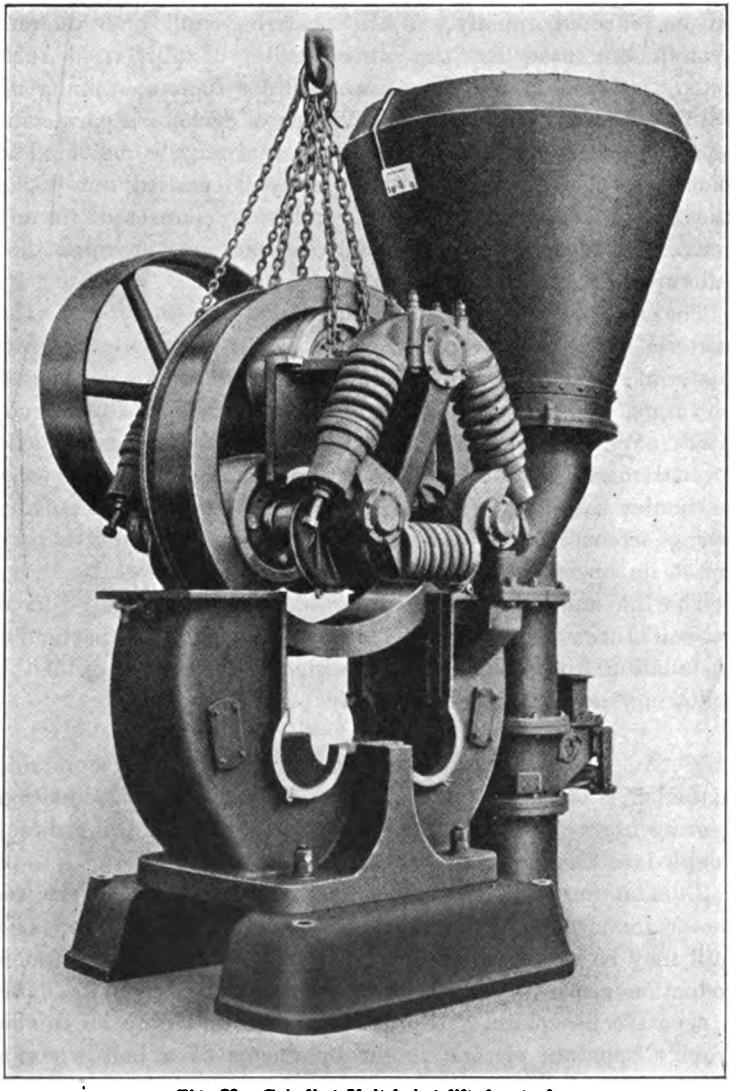

Fig. 20.—Grinding Unit being lifted out of Mill Housing.

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are provided with easily removable covers, enabling inspection to be effected rapidly. When the ring mill and vacuum system are used for the direct firing of pulverised fuel, separate drying plant is not essential for fuels containing up to 15 per cent. of moisture. Where a cyclone separator is added to the system in order that the fuel may be delivered to bins or other receptacles, drying may be carried out inside the grinding system if the air inlet is connected to any convenient source of heat, and means are provided for subsequently extracting the vapour.

The cost of operating the plant is exceedingly low, the material being conveyed automatically, after leaving the raw material feeder, by means of the air current; no bucket elevators, screw conveyors, or other mechanical devices are used. With the Rema vacuum system the fineness of the ground material remains constant, and cannot alter for any particular setting of the sifter vanes. There are no moving parts, screens, or sieves in the sifter to wear, and thereby upset its operation.

The fan and the mill are separate units, and may be fixed to suit the most convenient arrangement in any particular installation, the space required being very small. Any of the following methods of driving may be adopted:—

1. An electric motor may be supplied with a double extended shaft, and the mill driven by means of reduction gearing from one end of the motor shaft, the fan being direct coupled to the opposite end.

2. The fan may be direct coupled to a separate electric motor mounted on an extension of the fan baseplate. The mill may be arranged for driving by a separate motor through reduction gearing, the gearbox and motor being mounted on a separate baseplate. Alternatively, the mill may be driven from a separate electric motor by means of a belt when a special belt-tensioning device can be incorporated.

3. Where line shafting is available, belt drives may be employed for both mill and fan.

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Rema pulverising mills are adapted to suit any special requirements for large or small installations, either for a unit system, with direct firing, or for a central system, with indirect firing, to be used in conjunction with suitable storage bins, and pulverised-coal feeders. In large installations the mills may be run in batteries of several comparatively small sizes, where the fuel required varies from a large supply for a few hours only, to a comparatively small amount at other times of the day, the mills being started up as the steam demand increases in the same manner as additional turbines are started to deal with increasing load in power stations. The output from each mill can also be easily regulated to suit the varying load conditions, but to secure maximum economy the mills should be worked as near to full capacity as possible. On the other hand, one large mill may be used and a central system adopted, the coal being pulverised at a constant rate and delivered to storage bins, in which case the coal is fed to the boilers or furnaces by adjustable feeders to suit the load.

The largest single unit mill in the world, capable of pulverising 30 tons of coal per hour, is a Rema ring mill, and is used for pulverising fuel for firing water-tube boilers in an electric power station. The most satisfactory and economical pulverising results are obtained with heavy ring-type mills, in which the pulverising elements are forced against the ring by centrifugal force. These particular mills take a feed of one- or $1\frac{1}{4}$-inch material, and discharge it at the required fineness. Their superiority is based upon the combination of high fineness produced, large capacities, low power consumption, and low maintenance charges.

Refractories.

Higher demands are made, on the whole, on the refractory materials used in the construction of furnaces for pulverised-coal firing than for probably any other form of heating. Refractories used in pulverised-coal-fired furnaces are liable to

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mechanical abrasion and to chemical attack and actual solution, if the ash is deposited upon them in a viscous state. The essential requirements in a good refractory are "refractoriness" and constancy of volume.

Refractoriness implies the resistance of a refractory material to softening or partial fusion when heated; whereas constancy of volume implies that the refractory should not show signs of gradual shrinkage nor gradual exhaustion during continued use. One of the most disconcerting problems to be faced in connection with pulverised-coal firing is the high percentage of ash in many coals, frequently in excess of 15 per cent. This ash has in many instances been largely accountable for one of the most difficult furnace problems, namely, the erosion of side walls. In one particular case I have in mind the ash contained 18·5 per cent. of iron, and its fusing temperature was 2,000 degrees F.

The coal contained 5 per cent. sulphur. These particular chemical elements, when brought into contact with the refractories of the side walls at high temperatures and high rates of combustion, seemed to be just what was needed for melting the surface of the refractories. In other words, the ash became a flux for the refractory. Experiments to determine exactly the correct type of material have been carried out, and in consequence a refractory containing about equal parts of alumina and silica as the chief ingredients has proved eminently suitable.

Stretford Electricity Generating Station.

Trial of Buell Installation on a Babcock & Wilcox Water-Tube Boiler, 3rd May, 1927.

(Boiler has been in commission since early November, 1926.)
Duration of trial, 7 hours 10 minutes.

Fuel.

Total fuel consumed	22,260 lbs.
Fuel consumed per hour	3,105 lbs.
Description—Atherton Rough Dry Slack.	

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Analysis.	Dried Fuel. Per Cent.	As received. Per Cent.
Moisture	Nil	8·75
Volatile	35·20	32·12
Fixed carbon	56·25	51·33
Absolute ash	8·55	7·80
	100·00	100·00
Gross calorific value—B.Th.U's.	13,270	12,109

WATER.

Total water evaporated	183,711·3 lbs.
Evaporation per hour	25,633 lbs.
Temperature of feed economiser	125 degrees F.
Temperature of water leaving economiser	220 degrees F.

STEAM.

Pressure	178 lbs. per square inch.
Temperature	603 degrees F.

FLUE GASES.

Temperature of gases leaving boiler	559 degrees F.
Temperature of gases leaving economiser	342 degrees F.
CO_2 in flue gases	11·2 per cent.

DRAUGHT.

	Water Gauge.
Draught in combustion chamber	·12 inch
Draught at boiler outlet	·32 inch
Pressure of primary air supply { Left hand	3·8 inches
Pressure of primary air supply { Right hand	3·2 inches

DEDUCTIONS.

Actual evaporation per lb. of fuel	8 25 lbs.
Fuel consumption per cubic foot of furnace volume	1·70 lbs.
B.Th.U's. generated per cubic foot of furnace volume	20,600

HEAT BALANCE, based on gross calorific value :—

	Per Cent.
Efficiency of unit	83·9
Dry flue gas loss	8·7
Moisture loss	4·9
Radiation, carbon, etc.	2·5
	100·0

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Test Results.

Appended is a table showing the results of a test with the Buell system on Babcock & Wilcox water-tube boilers:—

Boiler Test with Pulverised Bituminous Slack Coal.

Test.	
Duration	8 hours
Date	13/9/26
Time started	8.10 a.m.
Time finished	4.10 p.m.
Boiler.	
Type	Water-tube
Make	Babcock & Wilcox
Heating surface	3,240 square feet
Number	5
Superheater.	
Maker	Babcock & Wilcox
Heating surface	483 square feet
Coal.	
Kind	Bituminous
From	Newcastle
Size and condition	Run of mine slack
Weight of coal, as received	8,640 lbs.
B.Th.U's. per lb., as fired	11,856
Coal consumed per hour	1,080 lbs.
Method of combustion	Buell pulverised-coal system
Analysis of Coal as Fired.	Per Cent.
Fixed carbon	51·57
Volatile matter	35·42
Moisture	2·13
Ash	10·88
Water.	Lbs.
Total water evaporated (actual)	81,100
Total water evaporated (from and at 212 degrees F.)	93,960
Water evaporated per lb. of coal (actual)	9·37
Water evaporated per lb. of coal (from and at 212 degrees F.)	10·86
Water evaporated per hour (actual)	10·125
Water evaporated per hour (from and at 212 degrees F.)	11,745
Pressure.	
Steam gauge pressure	140 lbs. per square inch
Pressure in mixing chamber	5 inches mercury
Draught in furnace	3 inches water

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Temperature.	Degrees F.
Feed water	182
Superheat (steam)	450
Flue gases	500
Outside	63
Boiler-room	72

Flue Gas Analysis, Last Pass.	Per Cent.
CO_2	12
O_2	7·1

Efficiency.	Per Cent.
Boiler and Superheater	86

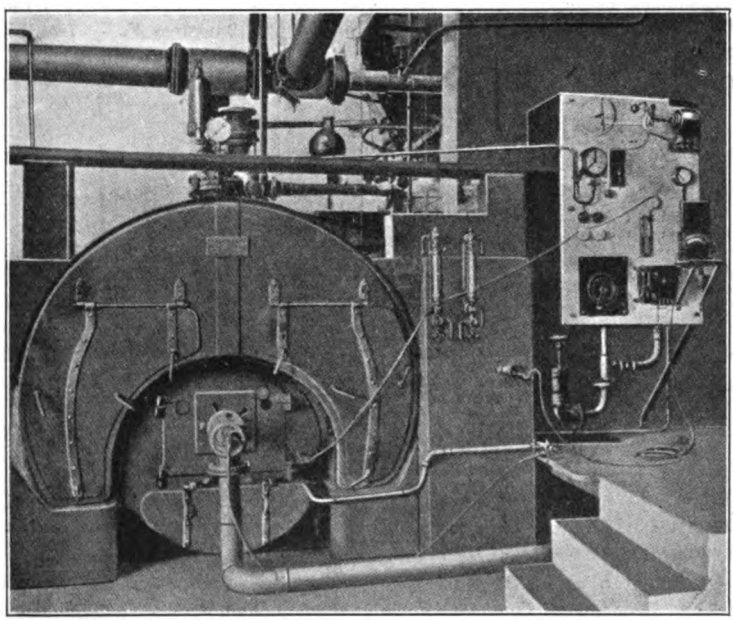

Fig. 21.—Buell Pulverised-Coal System fitted to Cornish Boiler, showing Automatic Control.

Test Results.

Appended is a table showing the results of a test with the Buell system on a Cornish boiler, Fig. 21. The boiler tested was of the return-tube type, 14 feet long by 6 feet 6 inches

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in diameter, fitted with one furnace tube 3 feet 6 inches in diameter and 65 tubes 2¾ inches in diameter. Three Galloway tubes were also fitted. The total heating surface was 920 square feet. Results of the test are as follow:—

Duration of test	8 hours 30 minutes.
Weight of water evaporated	23,030 lbs.
Water evaporated per hour	2,710 lbs.
Weight of coal burned	3,605 lbs.
Water evaporated per lb. of coal	6·39 lbs.
Average steam pressure	96·5 lbs. (gauge).
Average feed-water temperature	120 degrees F.
Evaporation factor	1·133
Equivalent evaporation per lb. of coal from and at 212 degrees F.	7·24 lbs.
Calorific value per lb. of coal as fired	9,410 B.Th.U's.
Thermal efficiency of boiler (assuming steam dry and saturated)	0·747

THE FUEL, AS FIRED, CONSISTED OF:—

21 per cent. which remained on a 100 mesh sieve.
27 „ „ „ „ „ 200 „ „
52 „ „ „ passed a 200 „ „

APPROXIMATE ANALYSIS OF THE FUEL.	Per Cent.
Moisture	8·8
Volatile hydrocarbons	45·7
Fixed carbon	37·9
Ash	7·8
	B.Th.U's.
Calorific value, as fired	9,410
Calorific value, dry	10,318

ULTIMATE ANALYSIS OF THE FUEL.	Per Cent.
Carbon	53·44
Oxygen	22·24
Hydrogen	6·88
Moisture	8·83
Ash	7·80
Nitrogen	0·51
Sulphur	0·31

PLANT FOR DUST REMOVAL ON LANCASHIRE BOILERS FIRED WITH PULVERISED COAL.

This plant consists of a manifold valve fitted by a branch line to the main steam pipe. From the manifold valve, pipes

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are arranged in the fire tubes, main return flue and side flues into the back main flue of the boiler, and nozzles are fixed to these pipes at equal distances apart. On the front of the manifold control valve is a series of notches which indicate the valve openings of the various pipes. By rotating the hand-wheel, the dust is ejected from one series of nozzles in the fire tubes to the next series of nozzles in the main return flue, and so on throughout the side flues into the back main flue of the boiler.

Cement Kilns.

It is estimated that 90 per cent. of the world's output of Portland cement is fired by pulverised coal. This has been brought about by the perfecting of the rotary kiln, which must use a flame produced by gas or pulverised coal, but owing to the superiority of pulverised coal no gas plants are now used. The modern rotary cement kiln consists of a slightly inclined steel cylinder mounted on steel rollers, the upper end of which is connected to a chimney stack, which permits the escape of flue gases. The raw cement or slurry is fed into the upper end of the kiln, and gradually moves forward as the cylinder rotates, passing through the hot gases from the pulverised-coal burner at the lower end until it eventually enters the intense flame, which raises the cement clinkers to between 2,800 to 3,000 degrees F., and calcines the material. After passing through the flame, the clinker is cooled and ground into cement. In order to withstand the intense heat, the kiln is lined with bricks of high refractory quality.

Various types of burner have been employed in cement kilns, both in this country and in America, with varying degrees of success.

One of the principal difficulties is to prevent the ends of the burners from collapsing, through getting excessively hot, but the greatest cause of trouble arises from the formation of clinker and coal rings due to the incomplete combustion of the

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fuel which fuses with the ash in the coal and certain constituents in the cement. This clinker ring forms at a distance of about 12 feet inside the kiln, thereby preventing the forward flow of cement, and may involve shutting down and digging out the ring, which sometimes destroys the lining.

Description.

The cement-kiln burner consists of a central air pipe, which conveys air at a suitable pressure to the tip of the burner, where it emerges into the core of the fuel cloud flowing into the kiln through the larger casing which is concentric with it. A sleeve can be moved axially with the pipe by means of the hand-wheel which is attached to the central air pipe. The axial movement of the sleeve alters the length and form of the flame.

A diaphragm plate with air inlets has a rotatable cover, which controls the quantity of air induced at the burner. It is hand operated from the firing platform in accordance with the requirements for more or less air for combustion. In addition to the sleeve, and pivoted thereto on two pins near its outer end, is a conical nozzle for deflecting the flame in any required direction. This nozzle is moved on its pivots by a screw and nut. When the flame has been deflected the required amount, its position, relative to the material flowing along and mounting the kiln lining, can be altered by rotating the hand-wheel, so that, when the proper direction of deflected flame has been found, any lengthening or shortening of the flame is done by moving the sleeve axially. Generally, when once adjusted to steady maximum working conditions, no further regulation is required. In fact, the steadiness of the flame, in spite of the unavoidable fluctuations in the kind of coal supplied to the burner, is one of the most valuable features introduced by its installation.

The uniformity of the coal-dust cloud, coupled with the fineness of air control and suspension of the particles, is a very valuable feature in the Buell burner, and is the main

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reason why it will burn lower-grade fuels than other burners commonly installed. Four secondary air pipes, carrying air at the same pressure as the air control pipe, assist in deflecting the flame in any desired direction, each pipe being fitted with a shut-off valve. The inflow of induced air protects the outer casing, which is of a conical form at the tip, from the fierce heat of the kiln. This casing is secured to the kiln hood, and ball joints are dispensed with altogether. The calcining zone is maintained at constant temperature, and the clinker falls in a regular stream of small pieces, about the size of hazel nuts, into the cooler.

In one case, after installing a Buell burner on a kiln 200 feet long, the average temperature of gases at the base of the stack over a 20 days' ordinary run, was diminished by about 135 degrees F., thus showing a considerable saving of heat units. At the same time, the heat of the output of the kiln was increased.

TESTS ON CEMENT KILNS FITTED WITH BUELL BURNER.

			Per Cent.
Kiln exit gases CO_2			25·8
„ „ „ O_2			1·3
„ „ „ CO			·1
Slurry moisture			37·3
Slurry. C_aCO_3			77·0
Standard coal consumption			25·9
Kiln exit gases, degrees F.	785		
Clinker leaving cooler, degrees F.	107		
Dissociation of carbonates	92,000		7·31
Heat contained in combustible gases	1,442		·11
CO_2 from raw materials	8,650		·68
Steam from slurry water	133,400		10 60
Gases of complete combustion	51,500		4 09
Excess air	3,340		·26
Clinker from cooler	1,100		·09
Total ascertained losses	291,432		23·14
Radiation and unaccounted for	34,908		2·77
	326,340		25·91

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SUMMARY.

Pulverised Coal for Metallurgical Furnaces.

Working results covering a period of many months are now available, fully confirming the great economies which pulverised coal has brought about in the firing of annealing furnaces, tunnel and batch, heavy and light forge furnaces, puddling, malleable-iron melting, copper refining and nickel reverberatory furnaces.

The highest attainable temperature for heating is obtained with pulverised coal because of the small amount of excess air required. Large amounts of excess air would greatly reduce the attainable temperature, and as the transmission of heat from the hot gases to the mass to be heated is the more rapid as the temperature gradient becomes more pronounced, it is fairly obvious that the higher the temperature in the combustion chamber the higher the efficiency of working; the small amount of excess air present reduces the loss of metal due to scaling. The heat produced in pulverised-coal-fired furnaces soaks through the metal more uniformly than in furnaces fired by hand, gas, or oil. Consequently, heated billets, ingots, plates, etc., can be worked for a much longer period without having to be reheated.

Pulverised Coal for Steam Raising.

The position of pulverised-fuel firing in relation to stoker firing continues debatable. The high efficiencies and complete flexibility attained with pulverised fuel have led the stoker designers seriously to consider ways and means of improving their class of manufacture. Boilers fired with pulverised coal have reached such huge dimensions that it is to be wondered if the race for supremacy between the two classes of firing can continue much longer.

The development of larger boiler units renders every feature of design—from the point of view of stokers—more difficult. Expansions, air distribution and control, together with heavy loads over long periods, are among the problems which

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increase with the size of units, and at best the breakdown hazards increase with the multiplicity of parts in the furnace. The extreme flexibility of pulverised coal gives it a strong advantage over the stoker-fired furnace. A mistake on the part of an operator such as to cause a departure from good combustion conditions or sudden increase or decrease of load, can easily be rectified by adjusting the air supply, dampers, etc., and bringing in or closing down the coal burners, whereas in the case of stoker-fired boilers such a mistake would require considerable time to rectify.

A changeover on a stoker-fired boiler from one kind of coal to another, say, 12,000 B.Th.U's. per lb. to 9,000 B.Th.U's., would simply interrupt the whole plant, reduce the efficiency, and bring down the evaporation, because a change in the quality of coal will produce a change in fuel-bed conditions which will not become apparent immediately, but will, as already pointed out, produce unfavourable conditions. With pulverised coal, the matter is entirely different. A drop to 9,000 B.Th.U's. from 12,000 B.Th.U's. merely requires an increase in the speed of the feeder worms and air supply, and the performance is carried on as before.

One of the practical advantages of pulverised coal is the much more perfect combustion. The average carbon content in samples of ash I have taken from different plants at different stages was from 0·40 to 0·74 per cent., whereas in stoker practice the loss due to unconsumed carbon in the ash varies between 10 and 40 per cent. In spite of the recent improvements in the design of stokers, which enable them to burn poor grades of coal very efficiently, they still lack the flexibility to be found in pulverised-coal installations, where it is possible to burn very low grades of coal irrespective of ash and volatile matter. Pulverised coal will work in an extraordinary manner with other fuels, whether blast-furnace gas, coke-oven gas, oil, or pulverised coke. Stoker-fired boilers are working in this country at 85 per cent. on the higher value of coal when taking into account air heaters, superheaters, and economisers. Such figures may be attained on a short test

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covering a few hours, but it is fairly obvious that they will not be weekly figures, all the year round.

Probably one of the greatest advantages of pulverised-coal firing is the high average daily working efficiency. Pulverised-coal-fired boilers have been running regularly at from 85 to 86 per cent. boiler efficiency, 89 per cent. having been obtained on short tests. Low fusibility ash in the various grades of coal does not occasion much trouble, in view of the tremendous step forward in the development of furnace design for pulverised-coal-fired boilers.

The higher settings, higher ratings, and higher efficiencies which obtain at present have placed a duty upon boiler furnaces which cannot be met satisfactorily by the refractories of common and standard use. This has led to the perfecting of a combination of water-cooled and refractory furnace, and one which would seem to present the greatest possibilities for the future.

The marked step towards the use of pulverised fuel in combination with air heaters makes possible very high ratings, and, naturally, very high efficiencies, which means a very intense heat in the furnace, making the necessity for water-cooled walls practically imperative. Another very important advantage derived from the use of pulverised coal is the extraordinary flexibility of the steam output of the boiler.

The advantages of pulverised-coal firing can be summarised as follows:—

1. Higher boiler plant efficiency.
2. Ability to burn low-grade fuels.
3. Perfect combustion.
4. Flexibility to meet varying loads.
5. Reduced stand-by and banking losses.
6. Greater ease of control.
7. Low labour costs.
8. Convenience of transport in the boiler house.
9. Low radiation losses.

With the ordinary methods of firing, radiation losses vary between 2·5 and 5 per cent., but in combustion chambers

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using pulverised coal, the maximum temperature occurs in the middle of the furnace, and hence the walls, usually fitted with absorbing elements connected to the boiler circulatory system, are comparatively cool, and consequently the loss entailed is only of the order of 1·5 to 2·0 per cent.

Pulverised Coal for Marine Purposes.

The introduction of the Buell forced-draught type of burner has opened up tremendous possibilities in the application of pulverised coal on board ship. Comparatively little has been done until recently, but, on the other hand, so much experience has been gained in other applications that the marine problem can be approached with every confidence. The most efficient and suitable types of bunkers, feeders, burners, pulverisers, and other equipment of a similar class have been proved by experience.

Boiler efficiencies obtained with oil have been duplicated, and this duplication has been accomplished in such a way as to render the operating problem no greater than that on the oil burner, and with a fuel having a B.Th.U. cost approximately one-half of that of fuel oil. Before the advent of the Buell burner, the average pulverised-fuel plant had a rate of combustion of less than a pound of coal per cubic foot of furnace volume, and the design of furnace allowed a flame travel of 20 feet or more, which permitted comparatively slow flame propagation.

The furnace of the ordinary Scotch marine boiler, being approximately 8 feet long up to the combustion chamber, which is about 3 feet deep, giving a total maximum flame length travel of 11 feet, prohibited the use of such systems of firing. A stream-line burner was an impossible part of the pulverised-coal plant equipment so far as marine application was concerned.

The Buell burner is so designed as to create turbulence of mixture, immediate ignition at the mouth of the burner, and complete combustion within 6 feet of the coal cloud leaving

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the tip of the burner. In the introduction of this type of burner, the means whereby pulverised coal can safely challenge the use of fuel oil on board ship, from the point of view of operating costs, can readily be seen. Pulverised coal has also the right to question the superiority of the Diesel engine's operating costs, and will have the advantage of a reasonable initial installation charge. It is quite possible to meet the challenge of the Diesel engine, not in terms of pounds of fuel per s.h.p. per hour, but in terms of cost per s.h.p. developed, and this with a plant where initial cost will certainly be much less than that of the Diesel engine.

Discussion.

Mr. ROBERT BROWN: As I have had considerable experience with a unit system of pulverised-coal firing, I wish to make a few remarks. No one can gainsay that the general principles of burning coal in pulverised form are fundamentally sound, but I cannot accept that the Buell system is the one and only system to use. There are three distinct stages in the use of pulverised coal—The preparation; the method of delivering the coal and air to the furnace *via* the burner; and, the combustion in the furnace.

Dr. Blythe describes three pulverising machines, two of which are of the pin disintegration type, and the third of German origin. Of the disintegration mills, it was found, over seven years ago, that no mill in which the coal is pulverised during its passage from the centre to the periphery of a disc where fixed and moving pins are arranged to intermesh, can be relied upon for consistent and continuous pulverisation; the degree of pulverisation falls off very rapidly with the wear of the pins, and it is impossible to retain the particles in the pulverising zone for a sufficient length of time. Also, the high speed of the discs necessary to effect pulverisation when the pins are new contributes to the wear and cost of upkeep, and, furthermore, the power consumption and maintenance are very high. With the atritor system, the primary disintegration is

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performed by hammers, the most efficient form of primary pulverisation, and the final state by passing inwards from the periphery to the centre, exactly the reverse of a disintegration mill, through rows of air beaters, which ensure fine and consistent pulverisation over the working life of the machine.

The Rema mill is not a unit in the true sense of the term. A unit system should fulfil certain definite conditions. It should be able to handle coal in almost any condition; it should be flexible, and controlled with ease and facility; and it should readily respond by way of output to any change in feed. If it is to work as a unit, its power characteristics must be such that the mill is efficient when working low loads, and in addition, it should be noiseless and dustless. The fuel for the Rema mill has to be crushed to the size of peas before it can be dealt with by the machine, and the limits of moisture are very quickly reached. Mills of this type are not flexible, and their response to variations in feed is very slow. Any alteration in feed to an atritor mill is communicated to the burner in 30 seconds, which is as it should be.

The power characteristics of the Rema mill are bad, since the greater part of the total power is required to rotate the mills, and if such are operated on low outputs they are grossly inefficient, *i.e.*, the power output curve is very steep. Finally, the Rema type of mill is terribly noisy, as all mills must be which crush coal by the pressure exerted between metal surfaces, such as the Bonnot, Sturtevant, and Rema constructions; it is difficult to maintain a cushion of coal between the metal surfaces under all conditions, and flats on rollers and ring soon tend to develop. A tramcar with a flattened wheel is almost heavenly compared with a pulveriser with flattened rollers and ring.

The repairs to such mills, while probably coming less frequently than with units, are costly to effect, take a large amount of time, and require special handling facilities, cranes, runways, and blocks. This involves lengthy stoppages for repairs, unless stand-by plant is provided. The largest atritor design will pulverise about 6,000 tons before requiring replace-

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Mr. Robert Brown.
ments, and its worn parts can be easily replaced in from one to 1½ hours. Mills of the Rema type are only really suitable for operating in conjunction with the storage system.

Dr. Blythe's statement that all pulverising plants have magnetic separators is not correct, the atritor having an air separator, which not only separates tramp iron but also other foreign matter which a magnetic separator fails to trap.

While it is not my intention to belittle the Buell burner, it is only fair to point out that, when compared with modern flare burners, the Buell burner cannot present the same intimate mixing of primary air and coal with secondary air. With a flare burner of the Riley type, it is possible to effect complete combustion in the open air. This has been done with an atmospheric temperature below zero when burning an 18 per cent. volatile coal; a feat not accomplished, within my knowledge, by any other burner, unless the Fuller well furnace is included in the list. Further, the Riley burner has an operating range of 10 to 1, so that a burner having a capacity of 6,000 lbs. of coal per hour can be reduced to 600 lbs., and yet maintain stable conditions. Its flame is bulbous in shape, and there is no torch effect, the whole appearance being turbulent. The combustion air, which may be highly preheated if desired, is under ready control, and the shape of the flame can be varied according to the conditions required. I mention this merely to show that, since the evolution of the Buell burner, the development of flare burners has been very rapid, and some exceptionally wonderful performances are now being obtained.

The combustion of powdered coal within the furnace is the final stage in the use of pulverised coal, and it is not practicable to use the same type of burner for each and every application. Dr. Blythe claims to avoid heavy wear and tear due to scouring action with the Buell system, and then proceeds to prove that the dust difficulty has been overcome by impinging the flame on to the bridge, thereby performing the act and achieving the result that he states can be avoided.

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Mr. Robert Brown.

While I have not actually seen a Buell metallurgical installation in service, I have seen the bridge wall fired by a Buell burner very deeply eroded and scoured. There is really no serious difficulty in firing smelting furnaces for high-grade ores and metals, and even for refining, etc., providing proper care is taken in the selection of suitable coal, obtaining the required fineness of pulverisation, and the correct design of furnace.

Referring to the boiler tests detailed at the end of the paper, the results obtained with relatively dry coals do not indicate very exceptional results. The percentage of CO_2 given in the tests are 11·2 and 12 per cent. respectively, whereas with a burner of the flare type, not less than 14 per cent. of CO_2 in the exit gases might be expected.

I was rather interested in the slide showing the application of the Buell system to the firing of Lancashire boilers, of which I have had some experience. It illustrated a very elaborate system of steam pipes to clear the ash and bridges to protect these pipes. Will Dr. Blythe say how long the boiler could be kept in action under these conditions, what efficiencies were obtained, and what was the cost of upkeep? The art of pulverised-coal firing is moving very swiftly. The design of pulverisers, burners, and furnaces is rapidly being improved, and performances are being obtained to-day which yesterday were scarcely thought possible.

Mr. William Brown (Member): In the second paragraph of his paper, Dr. Blythe states: "We, therefore, find advocates of innumerable systems, which range from oil and gas burning to low-temperature carbonisation, making clamorous appeals on behalf of individual proprietary processes . . ." Now, the subject is the Buell system of pulverised-coal firing, and I have no system to advocate. There may be many points in favour of pulverised-coal firing, but I have failed to grasp them so far, and any of the systems which I have seen, including the only one I have experimented with, have not produced effective results when the final cost

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Mr. William Brown.

is considered. In fact, my advice to anyone who is anxious to put down a pulverised-coal firing system is to install an oil-burning system instead.

Dr. Blythe describes the magnetic separators used with this system for the purpose of removing any tramp iron which may be in the coal. A few days after the paper was read, I was amused to come across an advertisement for another system which requires no separator. The advertisement reads: "No magnetic separator. Any tramp iron, or hard substance, entering the mill can do no harm; it helps to grind the coal." Here we have, in the paper, a description of the means employed to eliminate tramp iron, while with another system we do not require to do that at all. Now, where are we? Would it not be very much better to "stew" the coal and recover the by-products, and, if necessary, pulverise the coke and fire it in that form if steam is required, or otherwise take the by-products and burn them inside the cylinder?

Mr. J. L. Adam (Member of Council): I am very interested, from the point of view of a classification society, in some of the subsidiary problems arising from the use of pulverised-coal installation in ships. One such problem—and it is a very serious one—is the question of fire. We who have to do with ships, know that the question of fire in bunkers is a very important one, and that fire takes place in coal bunkers much more frequently than is desirable. It would appear from the paper, and from what experts have said about the ease with which pulverised coal can be fired, that there will be a great deal more danger in this respect when pulverised coal is used in ships. Another very important question has arisen in regard to the carriage of pulverised coal in bulk in ships bunkers. So far as I know, any installations that have been fitted in ships are of the type in which the coal is pulverised as it is used. It would be very interesting, therefore, if those who have experience with this fuel would state what are the probabilities of fire, and what precautions should be taken to lessen the risk.

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Mr. Gilbert Gunn.

Mr. GILBERT GUNN: I am a believer in coal-dust combustion, but only when it is possible to get from 15 to 18 per cent. CO_2 in the flue gases. In American boilers the coal dust is projected in at the top of the boiler, and falls down into a large combustion chamber. In falling, the carbon is gradually consumed, and then it begins to hover, and finally the ash is fused and drops to the bottom; but when coal dust is projected into a furnace in a horizontal direction, it has a tendency to fall down about seven feet away from the burner. I do not think there is a burner on the market which will supply a sufficient quantity of air intimately mixed with the coal dust to project it far enough into the boiler to effect complete combustion. To achieve this, an excess amount of air has to be admitted. In experimenting with oil burning some years ago, I found that a great excess of air beyond the theoretical quantity had to be admitted to carry the oil forward and prevent it from falling about seven feet away from the burner, at which point it usually falls and carbonises. The same thing happens with coal dust, and to prevent it I had to admit about three or four times the quantity of air actually necessary to get complete combustion.

Dr. Blythe gives the tests of two Babcock & Wilcox boilers, one with 11·2 and the other with 12 per cent. of CO_2, which is just about the percentage obtainable with the ordinary stoker, or even with hand firing, and that is not very good. Theoretical combustion requires about 12 lbs. of air per lb. of coal, and its equivalent percentage of CO_2 about 19, but in this case the weight of air is 24 lbs., which means that at least 12 lbs. of excess air must be heated up. If that is carried away at a temperature of 300 degrees F., and the "specific heat" be taken at ·2, I think it will mean that about 700 B.Th.U's. are carried out of the chimney per pound of coal consumed. If coal dust were completely consumed without any excess air, and the percentage of CO_2 were equivalent to, say, 18, the quantity of heat carried away would be only about half, or 300 B.Th.U's. These figures are, of course, only approximate, as I have had nothing to do with

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Mr. Gilbert Gunn.
boilers for some time, although I have had considerable experience in the past.

The whole trouble with burners is that a very large volume of air must be admitted to carry the coal dust forward until it is completely consumed, and I do not think the achievement of the Buell burner is very great when so much excess air is necessary. Another point which must be taken into consideration is that, in the Lancashire boiler, there is also a combustion chamber. Now, unless radiant heat can get directly at the iron plates, it is lost in some mysterious way, and I have never been able to find out why that is so, but until the whole flame is right inside the boiler flue with the radiant heat passing straight into the plate, the full efficiency is not obtained. With ordinary steam-jet oil burners, the steam used in atomising the oil at 120 lbs. per square inch, which is about as low as possible consistent with efficiency, is something between three and five per cent., and I imagine that grinding the coal will take a considerably greater percentage of steam. I have not any figures on that point, but still, for large installations and where the coal is projected in at the top of the boiler, I believe that coal dust has a future.

On the question of the danger of fire from pulverised fuel, I can relate an experience I had at a certain cement works at Oakenshaw, near Bradford. The plant had not been in operation for some months, and there was a large hopper containing about 12 tons of pulverised fuel. A workman opened the valve at the bottom, letting the whole contents down on to the firing platform, and immediately the dust went on fire from sudden contact with the air. Unfortunately, later on in the night a fairly strong wind arose, and what was not consumed of that dust was blown all over Oakenshaw, covering the fields and filling the dwelling houses.

Mr. James H. Paton, B.Sc.: I understand that Dr. Blythe has had considerable experience in testing different types of refractories. I should like to know which have proved to be the most suitable where pulverised fuel is used, and, a very

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important point, what are the maintenance costs for these refractories, and what is the usual time between renewals. There is no doubt that, when working with pulverised fuel at very high temperatures, maintenance costs will be an important item unless careful steps are taken to provide suitable refractories.

In some cases, and especially in the bridge of the metallurgical furnace, there appears to be slagging, but in other cases there is none; perhaps Dr. Blythe might be able to say something further on this point. Are there any plants now in operation which prove that the cellular walls mentioned in the paper prevent slagging? Dr. Blythe simply mentions, more or less casually, the cellular wall as a method of overcoming this trouble.

Where pulverised fuel is used, there is considerable trouble from dust, especially in the flues, and in this connection it would be interesting to know which are the best types of dust remover, what is the period of operation for dust removal, and if it is a very constant operation. I presume that the steam nozzles mentioned in the paper, for blowing out the dust from the flues, would require to be made of some special metal, in order to maintain their shape and strength under very high temperatures.

Is it advisable to use a very low grade of fuel, for such fuels contain large percentages of ash, and consequently a large amount of unburnable material has to be elevated and moved about at a cost which may more than counterbalance the saving from the use of these fuels? Anthracite coal has a very small volatile content, and I understand that in all types of pulverised-fuel plant there must be a certain volatile content in the fuel to ensure success. Is it possible to burn very hard anthracite coal in the form of duff, and can it be used with the Buell burner?

The temperature of combustion with pulverised fuel is likely to be very high. What effect has this on the general efficiency of the boiler? With reference to the Lancashire boiler, which is very common, especially in this part of the country, can any

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Mr. James H. Paton, B.Sc.
quality of coal be used, even the cheapest, and what is the chemical analysis of coals which have been used in Lancashire boilers with pulverised fuel?

Mr. R. D. Moore, B.Sc. (President): Undoubtedly the use of pulverised fuel is coming more into action, especially in the United States, where, last year, 40 million tons were used as against 10 million tons six years ago. The semi-anthracite coal obtained in the United States is especially suitable for this purpose; but British bituminous coal, and Scotch coal especially, is at a disadvantage owing to its ten per cent. water content, which requires to be largely driven off before grinding. In the actual working, when bituminous coal dust comes into contact with the furnace, distillation takes place, gas gathers round the coke centre, it is carried forward, and must first be burned off before the fixed carbon in the coke is affected by the oxygen surrounding it. The flame, therefore, from bituminous coal is a very long one, and on that account is not so well adapted to the conditions which obtain in a Scotch boiler. The Buell system undertakes to complete combustion within six feet of the burner, and if this is accomplished it is a very excellent result. It does not, however, seem to me to correspond with the general practice in steel works with gas and air. In a Siemens furnace, complete combustion cannot be secured within six feet of the ports.

Indications are not lacking that shipowners, shipbuilders, and marine engineers in this country are keenly alive to the possibilities of the use of pulverised fuel for marine purposes, and in this connection "The Shipping World," early this year, published a brochure dealing with the installation on board the "Mercer." This vessel, which is of 9,000 tons deadweight capacity, belongs to the United States Shipping Board's fleet, and is fitted with geared turbines, Scotch marine boilers with Howden's forced-draught, and has a complete equipment capable of burning pulverised fuel. She recently completed a voyage from New York to Rotterdam, and the tables published by "The Shipping World" show that, as against the

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older method of hand firing, she would save over £5,500 per annum, which would wipe off the cost of the pulverised-fuel installation in less than three years; while as compared with oil fuel, a saving of £8,000 per year might be anticipated. Comparing the "Mercer" with a motorship, the figures are not quite so convincing, for the latter without running expenses would show an advantage of £658, no allowance being made for the cost of repairs, upkeep, depreciation, and interest. With these considered, the pulverised-fuel-fired ship would show an advantage of £2,602 per annum, so it appears that the "Mercer" compares favourably with those of her sister ships in which Diesel machinery has been installed. If these figures given by "The Shipping World" are reasonably correct, as I presume they are, there seems to be a sufficient margin to make the installation of pulverised fuel worth considering.

There is no doubt that the efficiency of a pulverised-fuel installation depends largely upon the burner, of which there are several types in existence. The one in use in the "Mercer," and favoured in America, is the Peabody burner, which has given excellent results in practice. So far as I can see, there is likely to be a battle of burners, until eventually one is evolved which will give better results than the others. Dr. Blythe has shown that the Buell burner is easily regulated, and is very adaptable, and these are desirable advantages.

The inflammability of coal dust is a very important matter, especially in mines. My father was one of the first to realise the important part played by coal dust in colliery explosions, and I remember, about 40 years ago, when as a student I returned from Germany, he asked me to consider this question. A very serious accident had occurred at Udston Colliery, and I took samples of gas from the pit and tested them, after which my father was able to prove conclusively that the explosion was due to coal dust. Subsequently, experiments were carried out under conditions approximating to those of a mining roadway. On the ledges of a metal gallery about 300 feet long, coal dust was distributed, and at one end a shot was fired, causing sufficient

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draught to carry the dust along the whole length of the gallery. Although doors were provided to relieve the existing pressure, it was convincingly shown that once coal dust is disturbed it gets distributed over a very large area. I think, therefore, that, on account of its explosive qualities, coal dust for fuel purposes on board ship would require to be stored in spaces hermetically sealed. For storage purposes, it should be reckoned as a gas, and its carriage in bulk would have to be carefully considered.

Mr. R. Royds, M.Sc.: The paper deals with a very interesting subject, and one of practical importance to all engineers. I am particularly interested in the claims of boiler efficiencies under test with pulverised coal. The results of the tests are reported in a fair manner, and the efficiency for the boiler, as shown by the trial made on 3rd May, 1927, seems to be well substantiated by the heat balance. It should be remarked, however, that makers of chain-grate and other automatic stokers claim to obtain boiler efficiencies equal to those given by Dr. Blythe.

On page 416, Dr. Blythe states that the dust problem in metallurgical furnaces has been solved by allowing the burner to "spit" the fused ash or dust on to a bridge wall, and states that the viscous deposit protects the bridge bricks, whereas, on page 446, he mentions that, with pulverised fuel in boiler furnaces, the deposit of ash on the brickwork in a viscous state is very detrimental to the brickwork. He cannot have it both ways, and the confusion of claims in this respect seems to call for some explanation. Dr. Blythe explains how effective is turbulence in promoting rapid combustion of the particles of coal, by bringing the fuel and the oxygen into intimate contact. It is at least interesting to observe that the transmission of heat by convection between a gas and a surface, now well known to be explained by the Reynolds theory of heat transmission, depends upon a mechanism of molecular motion similar to that required to promote rapid chemical action.

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Mr. G. E. Hider.

Mr. G. E. Hider: Undoubtedly the important development in the economic use of coal has been impeded by over-anxious contractors, who have made rash promises without being in the possession of those practical data which must form the basis of any commercial proposition. These failures have held back this phase of engineering in South Wales, and this locality has suffered badly from the experiments of pioneers in this realm of engineering. I have had many opportunities of observing the strenuous efforts of Dr. Blythe to overcome these prejudices, and I am of the opinion that he is collecting reliable evidence as to the difficulties to be overcome, and is sparing no expense to find an efficient solution of such difficulties. His paper constitutes one of the very best attempts to put before engineers an outline of the essential principles in this system, and also a very straightforward statement as to the difficulties he has met and the means he has adopted to surmount them. He will expect to be criticised on some phases.

Obviously the most nearly perfect means of burning coal is by pulverising it. Dr. Blythe brings out that very clearly when he compares a one-inch cube of coal with the same cube pulverised, and shows that the area exposed to air is 1,000 times as great in the latter case. I do not think this phase should be considered as all important. I mean that if any system could be devised whereby that one-inch cube of coal could be surrounded with air throughout its period in the furnace, then perfect combustion could be obtained, although the rate at which combustion could proceed would be proportionate to the surface exposed to the action of the air. We all know that a very intense condition can be obtained in an ordinary Smith's fire, and that it is almost impossible to extend the principle of the Smith's fire to the burning of coal under a boiler. Therefore, we have to agree that it is well-nigh impossible to scrub each particle of coal with its requisite amount of air, except by pulverisation and the scientific admixture of air which the Buell design so efficiently gives.

These points are really important. One of the pioneers in

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Mr. G. E. Hider.

Great Britain in the application of powdered fuel to steam raising and other industrial problems is Mr. J. S. Atkinson, and because of the difficulties he experienced, he concentrated on the design of a furnace which would allow each particle of coal to be efficiently scrubbed with air without pulverisation, and he has undoubtedly produced a design for Lancashire boilers which must receive full consideration.

Dr. Blythe's description of the process of combustion shows how completely he has studied his subject, and it remains to discuss those difficulties to which he refers, and which we know cannot yet be considered as completely solved. His reference to violent mixing and turbulence in relation to solid injection oil-engines is interesting, but the experiments by Drs. Hartridge and Roughton established that fluids became fully mingled in a shorter space of time when the ingredients were confluent rather than contrafluent in their association, and this principle has been established in Diesel-engine design by Lt.-Col. Kitson Clark in his internal-combustion locomotive. The Buell burner appears to utilise these principles, and there seems to be no evidence of "collision," which at first thought appears to be necessary for intimate mixing.

The application to water-tube boilers is, of course, out of the experimental stage, but the economics are still hazy. It seems to be an easy and straightforward matter to analyse the alternative systems of pulverised coal and chain-grate stokers, but this elementary question is no nearer solution than it was five or six years ago. It is admitted that the capital cost of pulverising-coal plant is high, and that the drying and crushing costs may be from 2s. 6d. to 3s. per ton, and it follows that careful analysis is necessary before a decision is made.

In passing this phase, it may be useful to comment on the fact that many really sound engineers experience difficulties when comparing the fuel consumptions of boilers working under varying efficiencies. I have seen it stated that a boiler working at 60 per cent. efficiency burns 10 per cent. more coal than a boiler operating at 70 per cent. efficiency. Of course, this is wrong, and the correct figures are that, with 60 per cent.

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efficiency, 16·6 per cent. more coal is burned than at 70 per cent. efficiency, but the saving in raising the boiler efficiency from 60 to 70 per cent. is not 16·6 but 14·3 per cent. To take a case which might easily represent the efficiencies of two plants fired with (1) pulverised fuel and (2) chain-grate stokers, *i.e.*, 83 and 75 per cent. respectively, the chain-grate boilers would burn 10·66 per cent. more fuel than the pulverised-coal unit, and if coal were at 15s. per ton and an hourly evaporation of, say, 100,000 lbs. under analysis, then clearly the excess coal would be in the region of 60 tons per week, if the working period were 126 hours per week. The question then is: What are the every-day relative efficiencies and working costs for units up to, say, 100,000 lbs. per hour?

That the pulverised system allows varying conditions to be taken care of more efficiently is an acknowledged fact, and therein the system has a very distinct advantage, but it is probable that the difficulties due to a rapidly varying load will be at least partly taken care of by the installation of accumulators of the constant-pressure type in power stations, and the variable-pressure type when the conditions are suitable.

The application to Lancashire boilers is important, but it is necessary to face the facts clearly. On page 414, Dr. Blythe says:—"Evidently the Buell system eliminates the dust trouble." Would it not be more correct to say that auxiliary means have been designed to overcome the difficulty? A very complete dust-extraction plant is shown on the application to Lancashire boilers. This, of course, consumes a fair amount of steam, but I am of the opinion that such a system should form an essential part of any Lancashire boiler plant, so that its operating cost would not be debited to the Buell plant. I have recently had the opportunity of testing a Lancashire boiler fitted with the Buell system, and in the near future expect to carry through a more comprehensive test. Undoubtedly, higher thermal efficiencies can be obtained than with the ordinary open or forced-draught grates, and the interior of the external combustion chamber showed that the Buell burner is well-nigh perfect in its admixture of the coal and the air.

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Mr. G. E. Hider.

There remain, however, other phases to investigate before its application to Lancashire boilers can be accepted as being completely satisfactory. The very fact that combustion is perfect may be a drawback. The Lancashire boiler has developed without having been subject to the ideal temperatures obtained with the Buell system. In the region over the fire and near the bridge a very high rate of evaporation occurs, and very little work is done in the side and bottom flues. The flues of a Lancashire boiler are delicate units, and will not stand undue forcing.

With regard to the application to metallurgical furnaces, I know that this phase is receiving the close attention of Dr. Blythe and his associates. Maybe he is a little too optimistic in his paper, as many difficulties have yet to be surmounted. The question of suitable refractories is of vital importance, as is also the quality of the work put into furnaces which are to be subjected to the abrasive action of high temperature—high velocity gases; in this connection, the suspended type of arch must receive further consideration. In many cases a built arch, of a contour difficult to arrange with the suspended method, is required, but there are many cases in which the suspended arch would offer considerable advantages and minimise the trouble due to the action of the gases referred to above.

Mr. W. E. Philbrow (Member): It is to be regretted that Dr. Blythe did not use his undoubted knowledge of pulverised fuels, and his facility of expression, to deal more widely with the overall advantages and disadvantages of pulverised solid fuels, rather than restrict himself to an exposition of results with a proprietary detail forming a part of the whole problem.

The possibility of securing increased efficiency of the actual combustion process in furnaces when using pulverised solid fuels has been known to engineers for a very long time, and yet, judging by the proportion of furnaces working with these fuels in this country, and even throughout Europe, the overall commercial advantages have not been sufficient to justify

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universal adoption of the system. Dr. Blythe suggests that this apparent failure to use a system which is basically sound is due to the want of comprehensive knowledge of the science of combustion, and the unsuitability of plant for producing pulverised fuels. I submit, however, that the failure, if it is a failure, is due to causes far beyond the pulverising and combustion difficulties, and will be found to arise from the very small overall commercial advantages which can be secured, in proportion to the extra cost of plant, when balanced against the small cost of solid fuels as supplied untreated from the mines, in conjunction with the relatively small sizes of furnace in use until recently.

Dr. Anderson, in his treatise on "Heat," published in 1884, describes a pulverised-fuel plant and metallurgical furnace used in Woolwich Arsenal. This included a drying plant, ball and roller pulverisers, adjustable feeding devices, fan blast to mix the air and fuel, and a twin port burner with regulating devices to control the combustion. He mentions some difficulties, such as the pulverised fuel blocking at the curves of the feeding pipes, and the problem of the disposal of the ash (dust). The latter difficulty was overcome exactly as described by Dr. Blythe, namely, by impinging the flame on a wall of refractory material, to which the ash in a molten state adhered, and gradually flowed down to the slag pit. Dr. Anderson also expressed a very favourable opinion of the economic advantages possible by the use of pulverised fuel. However, the system has not made much headway for industrial work, while the system of converting solid fuels into gas before use in the furnace has so far proved to be the most economical.

These remarks apply, of course, to British conditions, where, until recently, the actual monetary cost of solid fuels and unskilled labour was very small; on the other hand, in America the conditions are reversed, and, in addition, prolific supplies of liquid fuels at low costs have forced the suppliers of solid fuels and furnace equipment to develop every possible means of reducing the working cost of solid fuels. Without question, British conditions are coming more into line with the

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Mr. W. E. Philbrow.

American, and we must be willing to adapt our methods to suit this change. While the results of comparative tests in metallurgical furnaces are astounding, they do not provide a true basis of the actual overall costs, and I would ask Dr. Blythe to submit more complete figures giving the capital investment and working cost for preparing the pulverised fuels. At a pulverising plant installed under American supervision in 1922, near Glasgow, the overall cost was about eight shillings per ton, which proved to be prohibitive, and the plant has been idle for a long time; one reason for this high cost was said to be the hardness and high ash content of local coals compared with American coals. Similar figures for the fuels used in the boiler tests submitted are also necessary to enable us to determine the actual advantages of the system.

To those who have had experience with the application of blast furnace or producer gas, and even liquid fuels to furnace work, the Buell burner does not appear to include any novel features other than the fuel used, as the methods for securing an efficient mixture, turbulence for rapid combustion, control of combustion, and direction of flame, etc., are common to most burners.

The pulverisers described also follow well-established practice, although it may interest members to learn that the Kek type with rotating discs, carrying fixed pins, was at one time made locally for dressing foundry sands, and has evidently been developed for a far wider field. Dr. Blythe does not include the preliminary crushing and grading plant, which is necessary to reduce the solid fuel to an average size before admission to the Kek type of pulveriser; possibly he anticipates that this grading may be done at the mine, where, I would suggest, the initial drying should also be carried out, and the prepared coal then delivered in covered wagons.

Too little space has been devoted to showing one of the greatest advantages of pulverised fuel, namely, the ease and compactness with which it can be transported and stored. For marine work, this advantage appears to me to outweigh all others. The crude method of loading the bunkers of a

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ship with coal of all sizes by up-ending a railway truck, or using a grab, or even hand shovels, the extra labour of hand trimming, and the resultant partly-filled bunkers, is appalling when compared with the method of supplying liquid fuel, and it should be just as easy to supply pulverised fuel. Possibly the provision of pulverised fuel may be considered a problem for the mining industry only, but if we hope to secure supremacy again for British coal, we must certainly supply it in a condition ready for the most efficient use, and I look forward to seeing stores of pulverised coal, comparable with the stores of liquid fuel, at all the principal world ports and industrial centres.

Mr. J. W. M. Topley: Since this paper has been addressed to shipbuilders, perhaps some particulars of a burner which has been used at sea may be of interest. The Peabody burners now in use on the s.s. "Mercer," which has already completed two double Transatlantic voyages, are shown in Figs. 22-25. Fig. 22 shows a marine Scotch boiler front with burners installed, Fig. 23 is a section of the burner, Fig. 24 shows the boiler in section with the burner in place, and Fig. 25 is a "ghost" picture of the air register shown in section in Fig. 23, with the optional oil burner in place. The diffuser disc shown at the end of the oil-injection pipe in the latter is withdrawn entirely from the zone of the flame when the oil burner is not in use; or the oil burner can, of course, be dispensed with altogether, leaving a perfectly clear throat. The whole thing swings clear with the hinged front—hinges not shown—when the door is thrown open. An intermediate alternative is to provide a simple oil "gun" which can be used with a small quantity of light oil for lighting up, thus taking the place of the oily waste torch. This is a convenience, but is by no means essential. Such a lighting-up gun has no diffuser. It will be observed that the vanes of the register are right at the back of the burner away from the flame, and that the part next to the flame is merely an open cast-iron throat having a circumferential slot through

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Mr. J. W. M. Topley.

which the pulverised fuel enters from the involute chamber surrounding it. This affords a very simple and robust construction.

The pulverised fuel enters the involute chamber tangentially, and acquires a whirling motion as it leaves. The secondary air, which is given a whirling motion as it passes through the vanes of the register at the rear end of the burner, enters the furnace flue through an already whirling hollow cylinder of

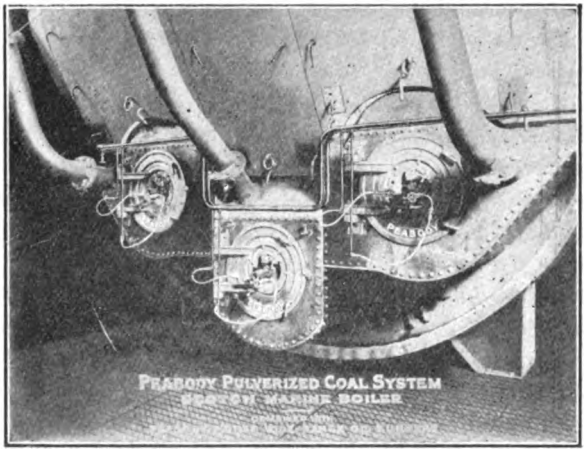

Fig. 22.

pulverised coal, and bursts out through the latter. This I believe to be a unique feature. In every other burner with which I am acquainted some at least of the secondary air is outside the entering fuel.

The point is often raised as to how the plant would be started up from absolute cold. The point does not arise, of course, where alternative oil burners are fitted, since a small supply of oil for that purpose is easily carried, very possibly light oil not requiring preheating. In the absence of any such facilities and of a donkey boiler, and of a supply of steam from a dock side, and on the really very rare occasions on which a

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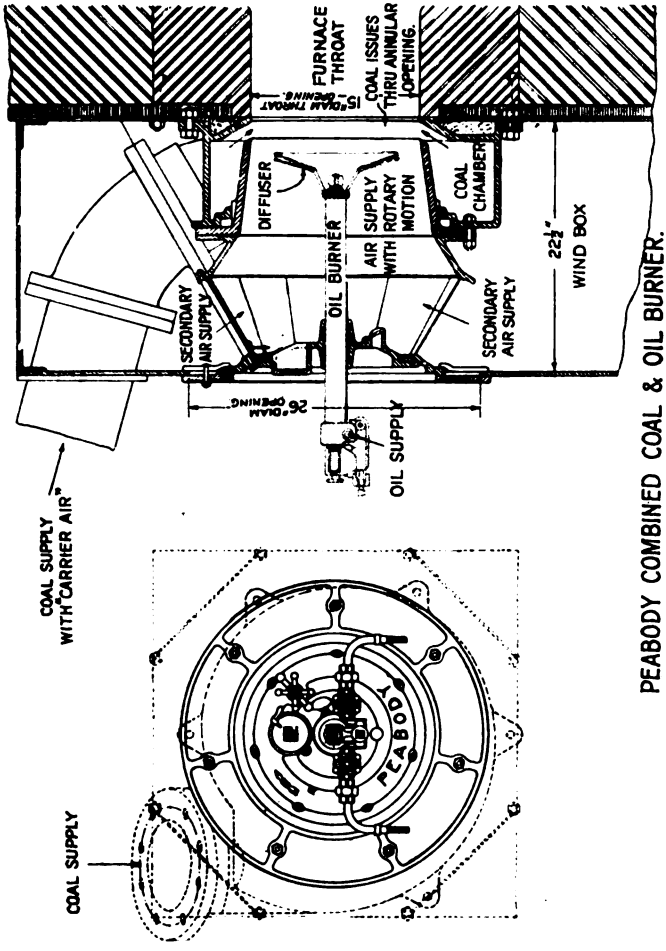
ship once in commission is allowed entirely to lose steam, a hand-stoked fire of unpulverised coal or wood can easily be



PEABODY COMBINED COAL & OIL BURNER.
OPTIONAL OIL BURNER SHEWN DOTTED IN SECTIONAL VIEW

FIG. 23.

started and maintained; a few fire bars would be handy, and probably available. A burner having a hinged door which can be swung open like any hand-fired furnace, leaving an

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unobstructed 15-inch throat, makes such a proceeding quite a simple one. For those who want to contemplate every possible contingency, it is evident that fires could be kept going in that way even were the whole pulverising plant, including the reserves, to be put out of action—a contingency in a properly-designed plant as unlikely as the loss of the propeller in a single-screw vessel.

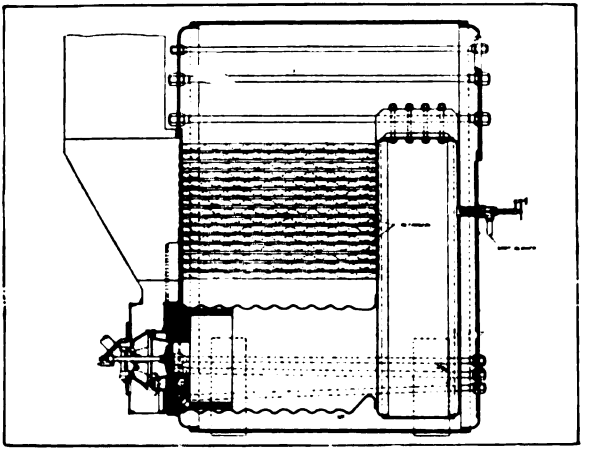

Fig. 24.

Doubt has been expressed as to whether a fuel of high ash content can be burned satisfactorily in the restricted flue of a marine Scotch boiler without causing slagging. On the first voyage of the s.s. "Mercer," the natural precaution was taken of bunkering a good coal; its ash content was low—some 7 per cent. On the second voyage, however, fuel containing from 20 to 25 per cent. of ash, with the moderate fusing temperature of 2,300 degrees F., was used. Even when the distributors were out of action, it was found that only small quantities of fused ash fell into the bottom of the flue and the back combustion chamber, and that in a very friable state, permitting it to be easily raked out through the lower cleaning door without touching the adjustment of the burner.

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Mr. J. W. M. Topley.

Mr. Gilbert Gunn has said that in the burners with which he is acquainted it is not possible to project pulverised fuel horizontally into a furnace without permitting the use of a very considerable excess of air. With the Peabody burner, at any rate, this is by no means necessary. A guarantee that it will work efficiently with no more than 35 per cent. of excess

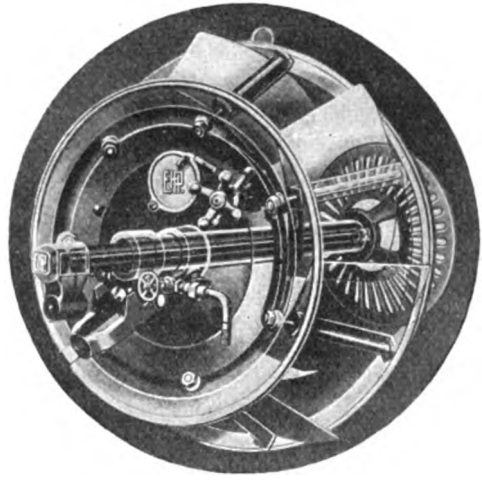

Fig. 25.

air is readily given, and I have seen many stations where the Bailey meters were set for 30 per cent. excess and the pointers were kept together with ease.

The tests at the Philadelphia Navy Yard on the marine Scotch boiler show under 25 per cent. surplus air, and stationary plants have shown even better. As a matter of fact, where conditions as to the possibility of slagging refractories permit, excellent combustion can be obtained with the very minimum of excess air.

Dr. Blythe: The points mentioned by Mr. Robert Brown in his reference to the pin disintegration type of mill are doubtless correct, and have caused the makers of the atritor

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pulveriser to carry out the primary disintegration of the coal by means of hammers. Seven years ago the Buell Co. (Australia), Ltd., used the hammer type of pulveriser, but results go to prove that the lowest maintenance costs are obtained by the ring roller type of mill and the air-swept ball mill. It was only after years of experience and development work that the Rema ring mill and vacuum system was perfected, and its advantages when grinding hard and semi-hard substances are so marked that other types, such as pin and beater mills, are not now recommended for the pulverisation of coal and similar materials.

Mr. Brown makes no mention of degree of fineness in pulverisation, although it has a very important bearing on the question of power consumption and output. The Rema plant can be easily adjusted to give any degree of fineness from coarse to superfine, and when once set for any particular fineness will automatically continue to deliver that grade, independently of any wear taking place inside the pulverising well itself. This is not the case with pin and beater mills. Mr. Brown is evidently aware of the falling-off in the degree of fineness with the wind-swept pin or beater mill, as the grinding elements wear. The usually accepted standard for grinding powdered fuel is 75 per cent. through a 180 mesh, but the following results can be obtained with the Rema plant:—

Coarse Grinding.		Fine Grinding.	
Degree of Fineness. Per cent.	Mesh of Sieve.	Degree of Fineness. Per cent.	Mesh of Sieve.
95	80	99·9	80
87·5	130	99·5	130
75	180	97·5	180
65	210	85	210

The power characteristics of the Rema mill compare favourably with other systems. In all systems, there is a constant loss due to the load taken by the fan. With the pinned case, beater type, and other high-speed mills, there must also be added another constant loss due to the windage

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set up by the grinding elements. These losses constitute a large proportion of the total power absorbed when grinding with high-speed mills. The slow speed of the Rema mill obviates this second source of loss. The power taken to revolve a standard Rema mill of 1,500 lbs. per hour capacity (exclusive of fan) when running light is 1·5 b.h.p.

This mill can handle coal in almost any condition, and in this respect is superior to the atritor, since wet coal or coke can be dried and ground simultaneously, assuming that the raw fuel contains a reasonable percentage of rough material, is free from clay, and that a suitable supply of hot air or waste gases is available. Further, if the raw material contains a proportion of dust which is fine enough to pass the burner, the system will separate this out, and only allow oversized particles to pass the mill for grinding. Over a wide range of output, the Rema plant will respond to changes of feed in from 30 to 90 seconds.

The size of raw material which can be fed to the Rema system is approximately ½-inch cube on the smallest mill, and 1-inch cube on the larger mills. With the later type of breaker feeder, however, material up to 1½ or 2 inches can be dealt with. In operation, the mill is not more noisy than other types, and is fundamentally different in design to the Bonnot, Sturtevant, and other ring roll mills referred to by Mr. Brown. A cushion of coal is maintained between the ring and rolls so long as material is fed to the mill, and flats should not develop with ordinary reasonable attention to the means provided for adjustment of the springs as the ring and rolls wear. As the speed is low, repairs are rarely required, and replacements are quite easily made, as the machine can be readily dismantled. New rolls and ring can be fitted to a three-ton per hour mill in about four hours, while if a spare unit, consisting of ring rolls, shafts, bearings, springs, and side plates assembled together, is available, the grinding unit can be lifted out and the spare one inserted in about half-an-hour. Adequate lifting facilities have to be provided, whatever type of mill is used.

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Dr. G. F. K. Blythe, B.Sc.

My reference to magnetic separators was essentially confined to high-speed mills of the Kek, W.A.C., and turbo types, as Fuller-Bonnot, Fuller-Lehigh, Rema, and atritor mills do not require separators to extract tramp iron and foreign matter.

I do not agree with Mr. Brown when he states that the Buell burner cannot produce the same intimate mixture of coal and air as the Riley burner. The design of the latter follows that of the Buell, but at the same time the mixing and scrubbing action of the air on the coal particles, by means of a plurality of streams, gives such an exact air control in the case of the Buell burner that the character of the flame can be changed from a reducing to an oxydising atmosphere within a few seconds.

I quite agree that it is impossible to use the same type of burner for every application of pulverised fuel. The Buell Company realised this, and overcame the drawback when they introduced the dispersive, non-dispersive, and forced-draught types of burner. The first and third give a short bulbous flame; hence their suitability for boiler units, while the second type gives a comparatively long flame, which is suitable for cement kilns, or where it is desirable that the maximum heat zone be some distance from the burner. Operating results prove that by slagging the ash, contamination of the metallurgical product is prevented, and provided high-class refractories are built into that portion of the furnace subjected to extremely high temperatures and slagging conditions, and the furnace is designed on correct lines, deep erosion and scouring should not take place.

Mr. Brown makes special mention of the proper selection of suitable coals for smelting furnaces dealing with high-grade ores and metals. In many cases the grade and class of coal were determined long before pulverised-coal firing was resorted to. The application of the latter invariably brings about a change in the grade of coal used, more often than not to one of a much lower grade. A careful selection of fuel for metallurgical furnace use need only be made in specific instances, and in special cases where the presence of ash and sulphur

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may be particularly inadvisable. It is necessary in the case of refining, malleable-iron smelting, open hearth steel-making, and for piling and bushelling furnaces, to use coal with an ash content below nine per cent.

The tests detailed in connection with the Stretford plant were not given with a view to suggesting that exceptional results had been obtained, but to show what could be obtained with the Buell system when operating on a water-tube boiler having a relatively small combustion chamber when compared with the average pulverised-fuel plant. Messrs. Babcock & Wilcox have recently put into operation, at the County of London Electricity Generating Station, Willesden, two water-tube boilers each of 75,000 lbs. actual evaporation per hour, using Buell burners. These boilers have evaporated at the rate of 90,000 lbs. per hour with a CO_2 content in the exit gases of 16 per cent., which compares very favourably indeed with the results quoted by Mr. Brown for the flare type of burner.

I can assure Mr. Brown that the system of steam pipes to deal with the dust in the Lancashire boiler plant is not so elaborate as he imagines. The boiler in question has been kept in operation for 126 hours per week for six months. The average working efficiency of the boiler was 75·1 per cent., and the cost of upkeep has worked out at £32 in six months.

I regret that Mr. William Brown has not grasped the points put forward in favour of pulverised-coal firing. I would again suggest for his consideration the following points in favour of pulverulent fuel, as compared with the use of, say, chain-grate stokers:—

1. Greater overall thermal efficiency, after deducting power absorbed by auxiliary machinery
2. Use of cheaper fuel.
3. Lower maintenance costs.
4. Reduction in ash disposal.
5. Lower operating costs.

Thermal efficiency may best be considered by studying the losses incurred from the entry of fuel into the furnace to the

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removal of the non-combustible matter from the furnace. The principal losses include—Unburnt solid or gaseous fuel, sensible heat of ashes and clinker, sensible heat of waste gases, and radiation.

The results of detailed tests carried out in one of the large power stations fired with pulverised fuel showed 0·74 per cent. as the average loss of unburnt carbon in the ashes. It is very difficult to obtain authentic figures for the loss caused by the amount of unburned and partially burned fuel in the ash and clinker with mechanical stoking, but in many power stations it is large, and quite often approaches 4 to 5 per cent. of the coal bill.

In a paper which Mr. W. S. Patterson read before the Yorkshire Section of the Society of Chemical Industry in 1923, he gave some interesting figures relating to the composition of the ash and clinker from fifteen different mechanical stoker plants. The amount of ash was found to vary between 5·2 and 40·48 per cent., corresponding to 0·75 and 19·10 per cent. of the original carbon in the coal. Out of the fifteen plants, nine had over 15 per cent. unburned carbon in the ash, and twelve had over 2 per cent. of the original carbon in the coal present in the ash, while ten had over 3 per cent., and six over 5 per cent. With pulverised-fuel firing, the direct thermal loss from excess air can be reduced 20 per cent. as compared with the best stoker performance. This corresponds to a gain in efficiency of about 2·5 per cent.

The conditions obtaining in a well-designed pulverised-coal-fired furnace are so effective that it is not a difficult matter to maintain an average of 14·5 per cent. CO_2 in the flue gas, corresponding to from 20 to 25 per cent. excess air. In the case of stoker firing, a large proportion of this air passing through the furnace does not come into contact with the fuel, and, therefore, a certain proportion of the coal mass is not scrubbed; in consequence, it is robbed of a certain amount of oxygen which is necessary to promote combustion. The effect of excess air, unburnt solid and gaseous fuel, and radiation collectively, is that it is possible to obtain as much

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as 10 per cent. increase in efficiency with pulverised-fuel firing as compared with stoker firing; there is also a gain in efficiency of from 1·5 to 2 per cent. from the sensible heat of the ashes and gases.

Mr. Brown's reference to magnetic separators is rather amusing. They are not used in ball mills or ring roller mills, but only in high-speed mills of the impact type, such as the turbo-pulveriser, Kek, W.A.C., and resolutor.

Mr. Adam refers to the question of fire in ships' bunkers. I do not advocate carrying coal in pulverised form on board ship; I prefer pulverising on board. The danger of spontaneous combustion is minimised, even if the coal is stored in bunkers, provided it is cold and perfectly dry, and a blanket of inert gas is passed into the bunkers. The system is as safe and reliable as that of oil firing, if a few reasonable precautions are observed, and correct design and principles are embodied in the equipment used.

Mr. Gunn alludes to large combustion chambers where coal is projected in at the top by means of a streamline flow type of burner. This method of boiler firing is slowly giving way to horizontally-fired boilers where burners of the turbulent flame type are used. The difficulty of the coal particles falling down about seven feet away from the burner is not met with in practice. There is no disputing the fact that turbulence in the furnace is absolutely essential to ensure intimate contact of fuel and air at the moment of ignition, and to sweep away the products of combustion, so as to enable the oxidation of residual coke particles to proceed. Turbulent types of burner are designed to work with 25 per cent. excess air, which has been proved in practice to be sufficient to project the coal particles far enough into the furnace to enable combustion to be so completed that less than one per cent. of combustible matter is left in the residual ash. The qualitative effects of turbulence in accelerating the rate of combustion are now fully recognised. Consequently, future designs of furnace will be developed in conjunction with burners of the turbulent type, and not the streamline flow type put forward by Mr. Gunn.

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Dr. G. E. K. Blythe, B.Sc.

I presume Mr. Gunn's experience in pulverised coal was gained many years ago, when fuel was pulverised by mills producing "lump dust," which was distributed intermittently into a strong air-blast and blown at a high velocity into the furnace. Many drawbacks were bound to be associated with such methods of firing, and it was the failure that attended the early attempts at burning coal in pulverised form that earned for the system some contempt among engineers.

I have dealt to some extent with the remarks made by Mr. Gunn on low CO_2 readings given in the test figures, in my reply to Mr. Robert Brown's criticisms. The fact that there is an economical limit to working at a high CO_2 must not be ignored. The refractories in present-day use would not, in a furnace of solid-wall construction, stand up for any length of time to a 15 per cent. CO_2. The introduction of furnaces with water-cooled surfaces has been the means of increasing the safe working limits of CO_2 in the exit gases. Mr. Gunn has apparently taken it for granted that with the Buell burner a very large volume of air must be admitted to carry the coal particles forward in order to effect complete combustion. I can assure him that very good results have been obtained with an excess of air never more than 25 per cent. The tendency in designing pulverising equipment, as applied to Lancashire boilers, is to dispense with the large external combustion chamber, and to pass the flame forward into the tubes instead of heating up a relatively large mass of brickwork external to the boiler.

Mr. Gunn mentions that a 12-ton hopper was allowed to remain full of pulverised coal for many months, and when the contents were brought into contact with the air, fire resulted. Due consideration and thought must be given to the quality of fuel stored. The length of time that storage is feasible or safe depends on the nature of the fuel, the temperature at which it is delivered into the storage bins, and its initial contents of moisture and volatile matter. High-volatile coals as used in cement works will naturally be more susceptible to fire than, say, anthracite.

Replying to Mr. Paton, I may say that I have found the

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most suitable refractory to be one containing the following approximate analysis:—

	Per cent.
Silica - - - - -	49·80
Alumina - - - - -	43·12
Titanic oxide - - - -	1·80
Ferric oxide - - - - -	3·28
Lime - - - - - -	0·70
Magnesia - - - - -	0·76
Alkalies - - - - -	0·48

The properties of silimanitic products have received my careful attention, and I have proved that they show pronounced resistance to ferruginous slag. The underload behaviour is far superior to that of a fire-clay brick. The maintenance costs of refractories vary between 3d. and 6d. per ton of coal fired, with a period between renewals of from 8 to 12 months. In furnaces fired with pulverised fuel it is very important to have suitable refractories, but unfortunately very little data are available regarding the effect of different conditions or combinations of conditions on different refractories. It is desirable to know the normal and maximum temperatures which occur on the surface of refractories in various parts of the furnace, from the standpoint of slag erosion, and to know the rate of change of temperature with time at the surface, from the standpoint of spalling.

The velocity of the furnace gases is of considerable importance, since the greater their velocity the greater will be the amount of slag carried to the furnace wall in a given time, and the greater will be their tendency to sweep the combination of slag and refractory from the wall, exposing a fresh surface for attack. When studying the slagging of refractories, it is of consequence to know the composition of the slag carried in the gases and deposited on the refractories All these points must be taken into account when specifying a high-class refractory for special duties. Buell plants have been installed in reverberatory tin-smelting, cupro-nickel reverberatory, and copper-refining furnaces, where the combustion

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chambers are designed of such sizes and capable of such heat liberation as to cause slagging to take place, with a view to robbing the combustion gases of the dust particles prior to their entering the furnace proper. These means were adopted to prevent the metals becoming contaminated with dust. On a boromite furnace and reheating furnace no slagging took place, as they were so designed as to cause the issuing coal clouds to pass from the burner over the furnace hearths at a high velocity. At the back of the furnaces, chambers were installed of such a size as to create a marked drop in velocity, which resulted in a deposit of ash therein.

One of the chief difficulties previously experienced in the firing of flame-tube boilers with pulverised fuel was the deposit of dust, but this has now been overcome by the introduction of steam-blowing nozzles, the period of operation of which will naturally depend on the ash content of the coals used. On the Lancashire boiler, Fig. 1, coal with an ash content of 15 per cent. required blowing every three hours. The 90 feet of flues were completely blown within five minutes. Calorised metal, refractory covered, has been proved to be quite suitable for withstanding the temperature stresses met with in pulverised-coal-fired installations applied to Lancashire boilers. Provided low-grade coals can be used within a short distance of the colliery, thereby minimising freight charges, it is advisable to use them; but when the distance is great, freight charges prohibit their use, as they have to be paid on a comparatively large percentage of non-combustible matter. I have burned coals in South Wales purchased at the pithead at 7s. per ton, railway charges raising the price to 8s. 6d. per ton.

Difficulty has been experienced in burning anthracite coals in pulverised form. Their low volatile content is an obstacle to ignition. I have burned anthracite billy duff successfully in a Stirling boiler at one of the anthracite collieries in South Wales, and that duff was considered unsaleable. The analysis of the coal was as under:—

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Dr. G. E. K. Blythe, B.Sc.

	Per cent.
Fixed carbon - - - - -	91·34
Volatile - - - - -	6·6
Ash - - - - -	2·06
Water - - - - -	—
Sulphur - - - - -	1·04

B.Th.U's. per lb., 15,314

Before anthracite can be burned successfully, an incandescent mantle must first of all be provided, either by means of oil firing or by the firing of bituminous coal. When the refractories are sufficiently incandescent and the air supply is correctly regulated, I have found no difficulty whatever in firing low-volatile coals with the Buell system. It is taken for granted, of course, that the pulverised coal is supplied in the proper physical state, as regards dryness, and that at least 85 per cent. passes through a 200 mesh. As Mr. Paton points out, the attainable temperature with pulverised fuel is very high. With pulverised-fuel firing the necessary air required for combustion is passed, under complete control, into the furnace with the fuel. The Buell burner thoroughly mixes the coal and air particles, and this effects rapid combustion, resulting in a high CO_2 in the flue gases, which may average 14·5 per cent., corresponding to about 25 per cent. excess air. With such an excess of air, the coal burnt causes a high furnace temperature, while in the case of solid-fuel burning, the presence of a large percentage of excess air considerably reduces the attainable temperature. An example will prove the effectiveness of the above facts. Suppose that the calorific value of a coal containing five per cent. of hydrogen, five per cent. of moisture, and 80 per cent. of carbon, has been determined in the laboratory to be 8,000 calories at a temperature of 20 degrees C. The heat given out by one kilogram is 8,000 calories, and clearly the highest possible temperature that can be reached by its combustion will be attained if it is spent entirely in heating the products of combustion, which will be 2·93 kilograms of carbon dioxide, ·45 kilogram of water from the combustion and ·05 from the moisture in the coal, making ·5 kilogram, and 8·47 kilograms of nitrogen. In heating these

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products to 250 degrees C., the assumed furnace exit temperature, 966 calories are used and 7,034 remain, and for each degree of further rise in temperature there will be expended in 2·93 kilograms of carbon dioxide, 1·234 calorie; in ·5 kilogram of steam, ·310 calorie; and in 8.47 kilograms of nitrogen, 3·033 calories—making a total of 4·577 calories. The attainable temperature will then be 7,034 divided by 4·577, which is equal to 1,530 degrees, to which must be added 250 degrees, making a total of 1,780 degrees C.

If this coal had been burnt, not with the exact quantity of air necessary to burn it, but with a 50 per cent. excess, there would have been an additional 5·5 lbs. of air to heat up. To raise this to 250 degrees C. would need $5{\cdot}5 \times 230 \times 0{\cdot}243$, or 307·4 calories, and would reduce the available heat remaining at that temperature from 7,034 to 6,727 calories; and it would add to the heat needed to raise the gases through each degree of further rise, $5{\cdot}5 \times 0{\cdot}358$ or 1·969 calories, making the total 4·577 + 1·969 or 6·546 calories. The resulting temperature would, therefore, be $\frac{6{,}727}{6{\cdot}546}$, or 1,028 degrees above 250, or 1,278 degrees C. The small amount of excess air used in a pulverised-fuel installation results in a relatively small volume of gas to be heated during combustion of the fuel, and consequently, the flame temperature of the fuel is greatly increased.

Mr. Paton asks whether any quality of coal can be used, even the cheapest, and what are the chemical analyses of such coals. I have used successfully coals with ash contents up to 37 per cent., and at prices varying between 10s. and 2s. 6d. per ton on pulverised-coal installations. Trouble was experienced with a heavy ash deposit inside the furnace in the case of the high ash-content coal, but nevertheless the combustion was efficient.

Following are two specimen analyses of coals used in a Lancashire boiler fired with the Buell system. On this particular boiler installation, over 26 grades of coal have been used in nine months:—

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Fuel Analysis I.

Contents of Coal—	As received. Per cent.	As dried. Per cent.
Volatile matter	8·91	9·20
Coke	87·93	90·80
Ash	14·07	14·53
Fixed carbon	73·86	76·27
Free moisture	1·57	—
Hygroscopic moisture	1·59	—

Thermal Values—	Available. As received.	Available. As dried.
Calorific value, B.Th.U's.	12,366	13,115
Carbon equivalent, B.Th.U's.	—	12,436
Pounds of water evaporated per lb. of coal from and at 212 degrees F.	12·81	13·58

Fuel Analysis II.

Contents of Coal—	Pulverised Coal. Per cent.	Unpulverised Coal. Per cent.
Moisture	1·47	2·05
Volatile matter, moist sample	13·69	13·64
Volatile matter, dry sample	13·89	13·92
Ash moist ,,	11·92	12·76
,, dry ,,	12·10	13·01
Fixed carbonaceous matter, moist sample	72·92	71·55
,, ,, ,, dry ,,	74·01	73·07
Thermal Values—		
Calories, moist sample	7,466	7,390
,, dry ,,	7,576	7,546
B.Th.U's., moist sample	13,439	13,302
,, dry ,,	13,637	13,583
Pounds of water evaporated from and at 212 degrees F., moist	13·82	13·68
dry	14·03	13·97

Mr. Moore refers to British bituminous coals and Scotch coals being at a disadvantage for pulverising owing to a ten per cent. moisture content. I can assure him that such a moisture content would present no great difficulty. The Fuller-Bonnot ball mill can deal very successfully with a 15 per cent. moisture content in the coals. With coal containing ten per

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Dr. G. E. K. Blythe, B.Sc.
cent. of moisture, the air would be preheated to a theoretical temperature of 208 degrees F. and passed into the mill. The reason why pulverised coal has not made progress for marine purposes is not the question of the suitability of coals, but of equipment. On the average plant, streamline flame type burners are installed, which allow a flame travel of 30 feet, and permit comparatively slow flame propagation. This results in large combustion chambers. The conditions on board ship are entirely unsuitable for this type of furnace, and to operate successfully on the furnace of the Scotch marine boiler, equipment had to be designed to burn the coal particles thoroughly within a space of about 11 feet without impingement of the flame on the back wall of the combustion chamber. Supplied with coal of the requisite degree of fineness and a correct admixture of air, the Buell burner is capable of completing combustion within six feet, depending, of course, on the size and type of the burner used.

Mr. Moore suggests that the danger of using pulverised coal is analogous to the danger existing from coal dust in a mine. A coal-dust explosion in a colliery working must be likened to the actual burning of pulverised fuel in air inside the combustion chamber of a furnace. It affords no ground for the suggestion that because of colliery explosions pulverised fuel is in itself a dangerous and explosive substance. Pulverised coal forms a highly explosive or inflammable gas only when it is intimately mixed with air. In the Buell system, the air required to create an explosive mixture is only introduced at the burner itself, prior to the coal clouds being projected into the furnace.

In reply to Mr. Royds, I may state that manufacturers of chain-grate and other automatic stokers claim to obtain boiler efficiencies higher than those given in the paper. The claims are met during the first few months of running, but are never maintained throughout the working year, as in the case of pulverised-coal-fired boilers where efficiencies of 85 per cent. have been maintained continuously, and 89 per cent. on spot tests on the higher value of the coals used. In metallurgical

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firing the combustion chambers are designed, in certain cases, to create slagging conditions, whereas in the case of boiler firing, designs are made with a view to keeping the ash in a flocculent state. I am pleased to note that Mr. Royds considers the efficiencies stated to be reported in a very fair manner.

I am in entire agreement with Mr. Hider when he states that pulverised-coal development has been impeded by over-anxious contractors. Rash claims have been made, but not substantiated in practice. It is very encouraging to me to have his remark on my attempt to lay before engineers an outline of the essential principles in pulverised-coal firing. I am still of opinion that the size of the coal particles does affect the rate of the combustion. The rate of combustion is, in fact, sensibly dependent on furnace design, burner design as affecting admixture of coal and air, and the degree of pulverisation, the idea being to obtain, within the furnace, conditions closely resembling mechanical gas.

Considering the application of pulverised fuel to boiler firing as against chain-grate stokers, the economies of the former method have been proved in practice. The reduction in percentage of excess air, heat losses due to combustible in the ash, low radiant heat loss, and the use of low-grade fuel, effect an increase in thermal efficiency compared with the chain-grate stoker, and result in producing steam at a lower cost. The difference in efficiency between the pulverised-coal-fired boiler and stoker-fired boiler has been proved to be in favour of pulverised-coal firing by as much as ten per cent. In view of Mr. Hider's remarks on the Lancashire boiler, it would have been more correct to say that, by adopting a system of dust extraction, the dust difficulty has been overcome in the Lancashire boiler fired on the Buell system.

The question of refractories for pulverised-fuel-fired furnaces received my closest attention at the very outset, and I have replied fully to Mr. Paton on the question of refractories. The suspended arch, as Mr. Hider rightly points out, will play an important part in furnace design, and shortly I hope to put into commission a furnace with a suspended arch.

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With reference to Mr. Philbrow's remarks, I still maintain that pulverised coal has not received the attention it merits, because of the want of a comprehensive knowledge of the science of combustion, coupled with the rash claims made in the early days as to the savings effected. Mr. Hider in his remarks bears out the latter contention. In recent years the marked step forward is sufficient proof that material economies can be effected, and in many cases savings of 30 per cent. in the fuel bill have resulted after the adoption of pulverised coal. In other cases, the installation of the system meant only an increase of five per cent. in the thermal efficiency Every case must be taken on its merits. It is impossible to give Mr. Philbrow a definite figure covering the cost of plant, since the requirements for each application have to be considered separately. In view of the progress in design of equipment and experience gained, specific guarantees are made for every pulverised-fuel installation. The maintenance charges for the Fuller-Bonnot mill (ball type) are guaranteed not to exceed 3d. per ton, the maximum kw. per hour being 14·8 per ton of coal at ten per cent. H_2O. With reference to Mr. Philbrow's remarks on the grading of coal, it has been my experience that when a pulverised-coal plant is installed the customer sends forward coals varying in size from $\frac{1}{8}$ inch to zero, and not the lump coal referred to. When run of mine coal is used, a combined feeder and crusher is installed in order to deal with lumps.

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AN INVESTIGATION INTO SOME EFFECTS OF COLD DRAWING ON THE STRENGTH AND ENDURANCE OF MILD STEEL.

By R. M. Brown, D.Sc., Ph.D.,
Member of the Institution.

21st February, 1928.

Introduction.

Cold-worked steel is of vast importance to the engineer. Cold-working operations include rolling, pressing, bending, swaging, drawing, punching, shearing, etc., and cold-worked materials are accordingly in use for the most diverse purposes and under many conditions of loading, statical and fluctuating. The present investigation is confined to mild steel which has been cold worked by drawing through dies, but somewhat similar effects may probably be produced by other methods of cold working, since, in most cases, the essential deforming forces are compressive.

The uses of cold-worked material are manifold, each object presenting its own problems which require special investigation, *e.g.*, in clockwork mechanism, where forces may be very small and size all-important, the problems are largely those relating to cold flow of metals; or cold work may be applied to produce specific physical properties as for high-tensile wire, and ropes, etc. Such problems are not specially within the scope of the present research. The investigation is confined to material which has been moderately cold-worked with a view to rendering it suitable for use in automatic machines, or to material which has been given a definite profile as required for some specific purpose.

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Cold-worked material has long been popular for use in automatic machines, largely because its smooth surface and its size, accurate within fine limits, caused minimum wear of cutting tools and little or no trouble in passing through the collets of the machine. Some of the "free cutting" steels so used were rather brittle, and the fear of brittleness has somewhat hindered the development of cold-drawn steel for important parts of machines and structures. This is especially true as regards "profile steel." Cold drawing lends itself readily to the mass production of bars of steel, exact to size and of most complex forms. Such bars may be cut into shorter pieces as required, and are ready for use with the minimum amount of machining and fitting. While the use of such profile steels is steadily growing in industry, the rate of development would probably be accelerated if more definite information as to the effects of cold drawing on the mechanical properties of steel were available to the engineer. The results given in this paper are submitted as a contribution to this desired information.

The properties desired of a good engineering material may be briefly stated as follows:—

1. Up to stresses which exceed the maximum working stress by a satisfactory margin, the stress-strain graph should be reasonably straight, and should show a high modulus of elasticity. Strain and deflection would then be small, and Hooke's law could be assumed without causing serious error. Exact proportionality of stress to strain is not essential, and the modulus may be a "chord modulus." "High" is purely a relative term.

2. The stress at which creep persists should be high, or the material should have a high creep limit.

3. The material should have a high endurance limit when working under alternating or pulsating stresses.

4. It should have a high impact value.

It is to be understood that the above properties refer to all

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kinds of stress of whatever nature, and should hold good at all temperatures for which the material is regarded as suitable.

Cold-worked material is intended for use at or near normal temperatures, and the research has been confined to such temperatures; condition 2 does not, therefore, arise directly, since the creep limit at normal temperatures does not differ by much from the ultimate strength as obtained from tests made at normal rates of loading. It will be shown later that, under high mean tensile-stresses, superimposed on a pulsating stress, condition 2 tends to merge into condition 3, and that the creep limit under such conditions of stressing may define the endurance limit.

It may be objected that the foregoing statement makes no reference to ductility, a property greatly desired by engineers, and measured, usually, by the percentage elongation and percentage reduction of area observed in a normal tensile test. It is believed that if the above requirements are fulfilled, the ductility will be sufficient for all constructional purposes; that is, where it is not desired to subject the steel to further cold-working operations, but no attempt is made to define "sufficient." The importance of ductility to the engineer has probably been exaggerated. Ductility is only in evidence after plastic flow has commenced—a condition which is not supposed to supervene in a good design. It may be regarded as a safety device in cases of unequal distribution of stress at sharp corners, or at machining, or casual scratches which may cause a concentration of stress. Under such conditions, ductility, by permitting of a local yielding, may help to equalise the stresses. So far, it has not proved to be possible to corelate percentage elongation or percentage reduction of area with the life of a part in service. High impact value and high ductility do not necessarily go together, and requirement 4 is regarded as being of the greater importance. For purposes of comparison, percentage elongation and percentage reduction of area are tabulated in all the tensile tests which follow.

The necessity for further investigation into the effects of

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cold working is clearly emphasised in recent text-books, many of which comment on the lack of definite information on this subject. Reference to such text-books indicates that the evidence as to the effects of cold work on endurance is, admittedly, insufficient in volume and contradictory in its statements, and these facts alone justify further researches.

Scope of the Research.

The object of the research was to obtain information, of direct interest to engineers and designers, on the effects of cold drawing on some of the properties with which they were chiefly concerned. The research, therefore, deals with some effects of cold drawing, and is not specifically concerned with causes of failure under any kind of stress, nor with theories underlying those failures. No new methods of testing have, therefore, been developed; standard methods and standard machines have been used throughout.

Cold drawing elongates the grain of the material, and thus changes the form of the structure. Such changes may be expected to cause corresponding changes in the properties of the material in service, or under test conditions, and the changes so produced may probably bear some relationship to the angle between the grain direction and the direction of the applied loads. Such changes in properties may be regarded as intrinsic changes produced by the cold working. Cold working also leaves the material in an internally stressed condition, and the internal stresses may also be expected to modify the test results. In any given case, therefore, it would appear that the test results measure the algebraic sum of the above effects.

It is not easy to determine the intrinsic effects of the cold-working process by direct measurement, but any machining operation, by removing stressed material, modifies the internal stresses, and the effect of this modification may be investigated by normal methods of testing. If, therefore, a cold-drawn bar be tested after having been turned down, or bored out, to different diameters, the effect of the relief of internal stress

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may be investigated, and if a sufficient number of tests be made, the effects of the structural change produced by cold working in modifying the properties of the material may be inferred. In considering the results, it should, of course, be noted that the grain elongation is not necessarily uniform over the cross-section of the bar.

The above considerations suggested that the work should be divided into five sections, as follows:—

1. Effect of cold drawing on internal stress and the relationship, if any, between percentage reduction of area in drawing and the distribution, and magnitude, of the internal stress.

2. Machining, by removing stressed material, modifies the internal stresses. An investigation was carried out to determine whether the redistribution of stress caused by reducing the outer diameter by turning, affected the properties of the material as revealed by statical tensile tests and by rotary bending tests in a Wöhler machine.

3. Effects of initial stress, tensile and compressive, on the endurance range as determined by the Haigh direct-stress machine.

4. Effect of grain direction in cold-drawn steel on tensile, Wöhler endurance, Izod impact, and hardness properties.

5. Investigation into the variation, if any, of properties over the cross-section of a bar of profile steel which would appear to have been irregularly cold-worked.

Internal Stress Distribution.

Material Used. Steel conforming to Air Ministry specification 2S1 was used. This steel had the following analysis:—

	Per Cent.
Carbon	0·29
Silicon	0·10
Manganese	0·52
Sulphur	0·03
Phosphorus	0·05

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Treatment.

The steel was annealed in the laboratory at 850 degrees C., and was cooled in the furnace. This treatment may not produce the most suitable structure for cold drawing, but the object was to secure uniformity, and subsequent tests showed that the material was uniform to a marked degree.

Drawing was carried out in a 10-ton Buckton testing-machine; soap was used as a lubricant. The die was fixed in the lower crosshead, and was drawn down the bar. Autographic diagrams were drawn for each specimen, and the amount of cold work estimated. The mean values obtained from the drawing tests are given in Table I. The rate of drawing was about 3·3 inches per minute, and the reduction was carried out in a single pass in each case.

Table I.

Original Diameter. Inches.	Reduced Diameter. Inches.	Reduction of Area. Per Cent.	Mean Pull. Lbs.	Work done. $\frac{\text{In. Tons}}{\text{In.}^3}$
·5740	·5424	11·00	3,850	7·48
·6330	·5553	23·05	8,070	14·83
·6962	·5592	35·50	13,020	23·68

The relationship between work done and percentage reduction of area is shown in Fig. 1.

In a paper read before this Institution in 1925,* it was shown that with mild steel cold-drawn under similar conditions, the effect of ageing on the tensile properties was very small after a lapse of at least three months. All the material used was, therefore, aged for a longer period before being tested; in some cases check tests were carried out after two years ageing, and such tests showed no material differences.

The method adopted to determine the internal stress distribution was that due to Prof. Heyn. Marks were cut on test specimens at distances of four inches apart. Four such gauge

* Trans. of the Institution, vol. lxviii, p. 362.

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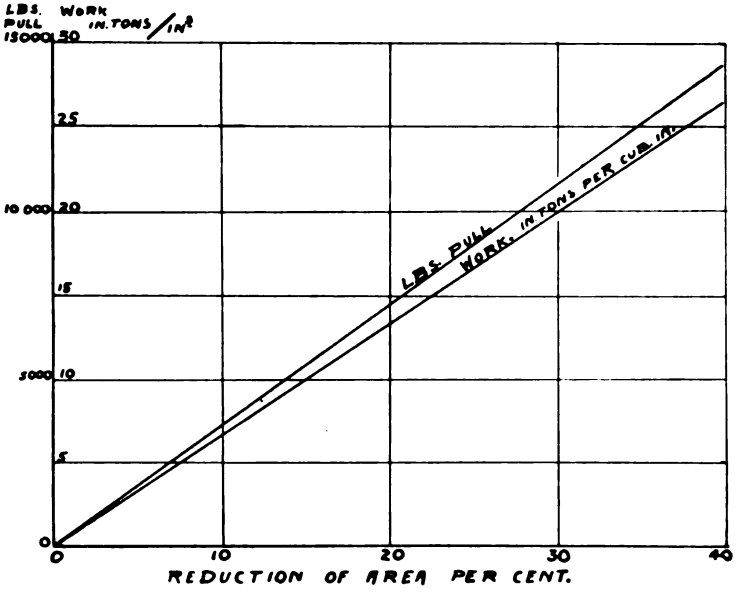
lengths at opposite ends of mutually perpendicular diameters were measured on each specimen, and the mean change of length noted. The diameters of the specimens were reduced by small decrements, and the change of length measured after each machining operation. Machining was carried out as gently as possible, to reduce to a minimum the effects of



[Fig. 1.

machining work. The specimens were placed on the table of a comparometer, reading to ·001 mm., and were measured on the following day. A standard time interval was allowed to permit of stress redistribution, and to allow the specimen to assume the same temperature as the measuring machine. No correction was made for temperature variations, as it was assumed that the leading screw of the machine and the specimen were at the same temperature. The temperature variations over the series did not exceed three degrees F.

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Let a_1 = area of the 1st element machined off.
a_n = area of the nth element machined off.
x_1 = change in length due to machining off 1st layer.
x_n = change in length due to machining off nth layer.
f_1 = mean stress on 1st ring.
A_1 = area before machining.
A_2 = area of core after machining off the 1st layer.
L = gauge length.
X = change of length as measured from original conditions.

Then:—Total force in 1st annulus = $f_1 a_1$.

Removal of this load from core A_2 causes an increase of length of x_1.

$$\therefore \text{ Unit change in core stress} = \frac{f_1 a_1}{A_2}.$$

$$\therefore \frac{\frac{f_1 a_1}{A_2}}{\frac{x_1}{L}} = E,$$

or

$$f_1 = \frac{EA_2 x_1}{a_1 L} = \text{stress intensity in 1st ring} \quad - \quad (1)$$

Similarly for 2nd annular ring,

$$\frac{f_1 a_1 + f_2 a_2}{A_3} = \frac{EX_2}{L},$$

or

$$f_2 = \frac{E}{L}\left(\frac{X_2 A_3 - x_1 A_2}{a_2}\right) \quad - \quad - \quad - \quad (2)$$

Equation (2) solved for each element removed, gives the approximate stress distribution over the cross-section of the original bar. Equation (1) has been solved for each succeeding element, in order that an approximate value of the skin stress after machining to a reduced diameter may be given. The values so obtained have been considered in relation to the effects of test diameter and machining or test results.

The results are given in Table II and in Figs. 2, 3, and 4. The stresses were calculated for E = 12,850 tons/in², a value

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Table II.

Internal and Skin Stresses.

+ Denotes tension.

Reduction of Area. Per cent.	Diameter. Inches.	Internal Stress. Tons/In.²	Total Load on Annulus. Tons.	Skin Stress. Tons/In.²	Diameter. Inches.	Internal Stress. Tons/In.²	Total Load on Annulus. Tons.	Skin Stress. Tons/In.²
	·5405				·5404			
	·5195	+23·84	+·4172	+23·84	·5202	+26·07	+·4379	+26·07
	·4993	+19·92	+·3282	+21·89	·5006	+19·88	+·3122	+22·42
	·4784	+16·27	+·2602	+20·05	·4807	+16·81	+·2589	+20·62
	·4557	+13·62	+·2274	+19·13	·4552	+14·69	+·2733	+20·26
	·4350	+10·42	+·1501	+18·33	·4346	+ 8·86	+·1276	+16·73
	·4142	+ 0·18	+·0025	+ 9·39	·4139	+ 6·31	+·01377	+14·62
	·3943	− 1·26	−·01601	+ 8·85	·3953	+ 2·37	+·02797	+13·53
	·3760	+ 1·46	+·01606	+12·71	·3753	− 2·98	−·03636	+ 9·25
	·3550	− 6·02	−·07276	+ 6·19	·3550	− 6·40	−·07418	+ 7·05
11·00	·3355	− 3·09	−·03275	+10·03	·3351	− 3·78	−·04086	+10·50
	·3155	− 7·85	−·07997	+ 6·44	·3154	− 9·59	−·09406	+ 5·90
	·2958	− 9·65	−·09109	+ 5·50	·2958	−10·16	−·09559	+ 6·13
	·2754	−10·00	−·09170	+ 5·90	·2754	−12·20	−·1119	+ 4·69
	·2547	−12·51	−·10760	+ 4·31	·2545	−13·45	−·1166	+ 4·34
	·2344	−13·38	−·10430	+ 4·18	·2344	−13·96	−·1079	+ 4·69
	·2150	−14·41	−·09858	+ 3·86	·2152	−16·24	−·1100	+ 3·20
	·1954	−16·33	−·10330	+ 2·66	·1956	−15·88	−·1003	+ 4·19
	·1751 Core estimated from graph	−17·10 −18·6	−·10100 −·4474	+ 2·51	·1759 Core estimated from graph	−18·90 −19·60	−·1085 −·4758	+ 2·07
	Out of balance +·0555				Out of balance −·02441			
	·5577				·5575			
	·5255	+17·74	+·4878	+17·74	·5333	+19·03	+·3959	+19·03
	·4995	+14·30	+·2988	+16·62	·5085	+15·39	+·3109	+17·17
	·4761	+10·78	+·1931	+14·82	·4800	+12·85	+·2853	+16·32
	·4536	+ 9·58	+·1581	+15·09	·4530	+10·36	+·2041	+15·86
	·4240	+12·90	+·2619	+14·66	·4223	+ 5·76	+·1210	+13·19
	·3940	− 6·64	−·1155	+10·23	·3963	+ 1·90	+·03211	+11·24
23·05	·3505	− 1·96	−·05342	+ 8·46	·3679	− 0·76	−·01284	+10·59
	·3250	− 3·68	−·04985	+ 9·19	·3405	− 3·69	−·05656	+ 8·92
	·2969	− 4·24	−·05817	+ 7·47	·3117	− 2·76	−·04060	+ 8·06
	·2777	− 8·50	−·07352	+ 7·73	·2896	− 8·75	−·09135	+ 6·79
	·2487	−12·32	−·1478	+ 5·10	·2695	− 9·46	−·08354	+ 7·30
	·2262	− 8·20	−·06805	+ 5·35	·2491	−13·08	−·1082	+ 7·57
	·2004	−15·60	−·1377	+ 4·02	·2300	−15·63	−·1122	+ 5·05
	·1718	−17·70	−·1458	+ 3·32	·2080	−14·74	−·1118	+ 3·62
	Core estimated from graph	−19·8	−·4587		·1884 ·1675 Core estimated	−17·00 −17·78 −19·8	−·1035 −·1039 −·4360	+ 3·70 + 3·78
	Out of balance +·09119				Out of balance +·08882			

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TABLE II—*Continued.*

Reduction of Area. Per cent.	Diameter. Inches.	Internal Stress. Tons/In.²	Total Load on Annulus. Tons.	Skin Stress. Tons/In.²	Diameter. Inches.	Internal Stress. Tons/In.²	Total Load on Annulus. Tons.	Skin Stress. Tons/In.²
35·50	·5579				·5578			
	·5372	+ 6·79	+·1201	+ 6·79	·5372	+ 6·65	+·1170	+ 6·65
	·5170	+ 7·14	+·1199	+ 7·68	·5163	+10·74	+·1869	+11·26
	·4951	−11·77	+·2060	+12·90	·4955	+12·73	+·2100	+14·19
	·4746	+ 6·11	+·09469	+ 8·44	·4745	+ 8·82	+·1403	+11·49
	·4519	+ 4·82	+·07952	+ 7·85	·4510	+10·35	+·1770	+10·80
	·4303	+ 6·58	+·1007	+10·43	·4290	+ 1·59	+·02416	+10·47
	·4108	+ 2·49	+·03137	+ 7·35	·4083	+ 2·36	+·03232	+ 7·86
	·3904	+ 3·43	+·04390	+ 9·11	·3910	+ 2·33	+·02517	+ 9·13
	·3705	+ 0·69	+·00821	+ 7·30	·3703	− 0·81	−·01004	+ 6·77
	·3505	+ 0·01	+·00135	+ 7·50	·3502	− 2·83	−·03212	+ 5·55
	·3302	− 3·14	−·03400	+ 5·16	·3303	− 5·80	−·06159	+ 3·25
	·3109	− 6·04	−·05876	+ 2·92	·3104	− 6·95	−·06936	+ 2·42
	·2904	− 3·72	−·03596	+ 5·61	·2876	− 6·11	−·06555	+ 3·61
	·2703	− 6·29	−·05555	+ 3·88	·2703	− 5·26	−·03977	+ 5·06
	·2551	− 6·67	−·04196	+ 4·06	·2549	− 8·45	−·05392	+ 3·22
	·2277	− 8·59	−·08906	+ 2·67	·2285	− 9·82	−·09811	+ 1·71
	·2103	− 8·48	−·05089	+ 3·45	·2100	− 8·49	−·05417	+ 3·16
	·1891	−10·23	−·06792	+ 2·41	·1903	−10·41	−·06433	+ 1·85
	Core estimated	−11·4	−·3200		Core estimated	−11·4	−·3241	
	Out of balance + ·05164				Out of balance + ·03979			
Annealed	·6324							
	·6244	+ 3·20	+·02496	+ 3·20				
	·6158	+ 4·26	+·03579	+ 4·33				
	·6053	+ 2·89	+·02918	+ 3·10				
	·5957	+ 0·73	+·00664	+ 1·23				
	·5552	− 0·53	−·01940	− 0·18				
	·5145	+ 0·17	+·005797	+ 0·49				
	·4138	+ 0·51	+·03743	+ 0·91				
	·3144	− 1·60	−·09088	− 0·70				
	·2097	− 0·21	−·009046	− 0·18				
	Core estimated	− 0·21	−·007247					
	Out of balance + ·013217							

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obtained from stress-strain graphs as giving, approximately, the mean value for the chord modulus for stresses up to values estimated as existing in the material.

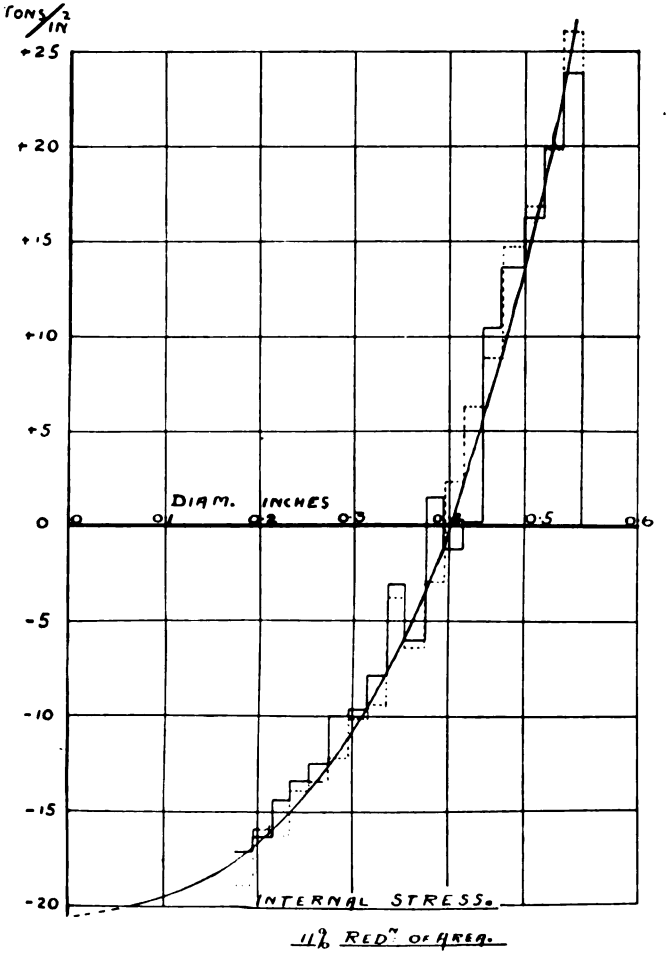

Fig 12.

The graphs 2, 3, and 4 show the calculated stresses obtained by equation (2) plotted as uniform over the annular

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ring which was machined off. Results of two tests are shown on each graph. The agreement between the stresses in corresponding pairs of specimens is remarkably close, although a

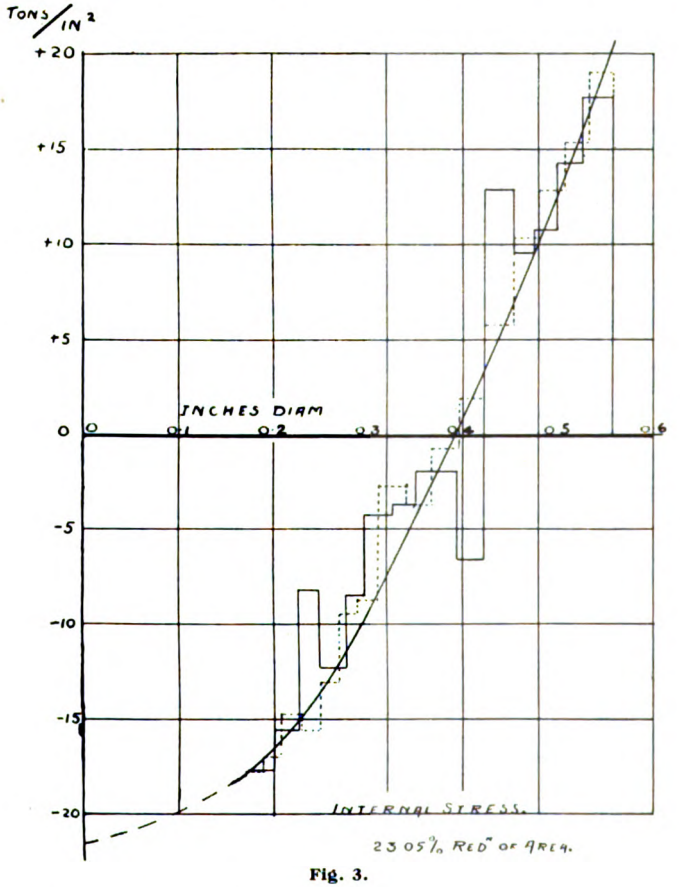

Fig. 3.

few discrepancies are observable in Fig. 3. The two specimens in this case were tested at different times, although the bars were approximately the same age. In other cases the bars were tested and machined together, and were, therefore, subjected to, as nearly as possible, identical treatment. The

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method is probably not capable of a very high degree of accuracy, owing to certain disturbing factors of unknown influence, such as the amount of work done on the specimens and the heating effects caused by machining. With specimens machined at the same time and subjected to, as nearly as possible, the same treatment, closer agreement is possible.

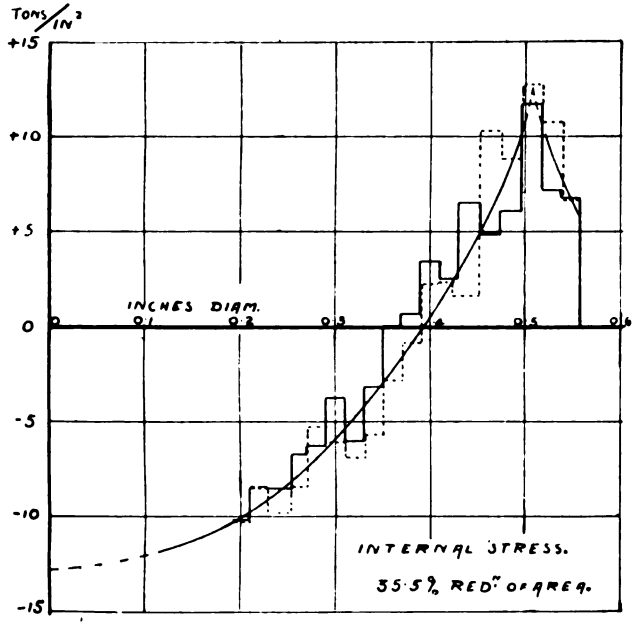

Fig. 4.

The graphs may be regarded as giving an approximation to the internal stress distribution caused by cold working. Approximate mean curves have been drawn on the graphs, and, for convenience in comparing results, these have been superimposed in Fig. 6. For the purposes of comparison, Fig. 5 shows the results obtained by machining an annealed bar. The annealed bar is approximately stress free.

The bars were obtained from the makers in the annealed condition. The preliminary tests already referred to showed

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that the hardness and tensile strength were not uniform over the length of a bar. This was probably due to the bars being annealed as a batch, and the ends of the bar, by tending to become spread out, cooled more quickly, and were, therefore, perceptibly harder than the central portions. The material was reannealed in short lengths under laboratory conditions before being used. The annealed specimen had, therefore, been doubly annealed before machining.

Two interesting facts may be noted from the diagrams. 1. The magnitude of the internal stress is reduced as the severity of the cold work is increased. 2. The maximum tensile stress is not always at the outer skin.

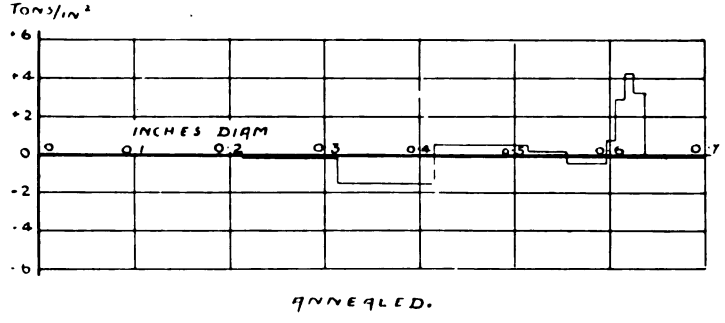

Fig. 5.

The reduction of internal stress with increase of cold work may, at first sight, appear to be an anomaly, but a rational explanation can be offered. The internal stress produced as a result of cold flow in a material depends, not on the amount of flow which has taken place, but on the elastic recovery or the "elastic afterworking" of the material after the removal of the deforming force. A perfectly plastic material would assume the form impressed on it, and could be subject to no internal stress when at rest. A material which was truly elastic within the range of any stresses applied to it, would show complete restitution of energy of deformation and recovery to its original form and dimensions on removal of the distorting forces. All metals and alloys are imperfectly elastic

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and imperfectly plastic under all conditions; they show, to a greater or less extent, the phenomenon of elastic afterworking,

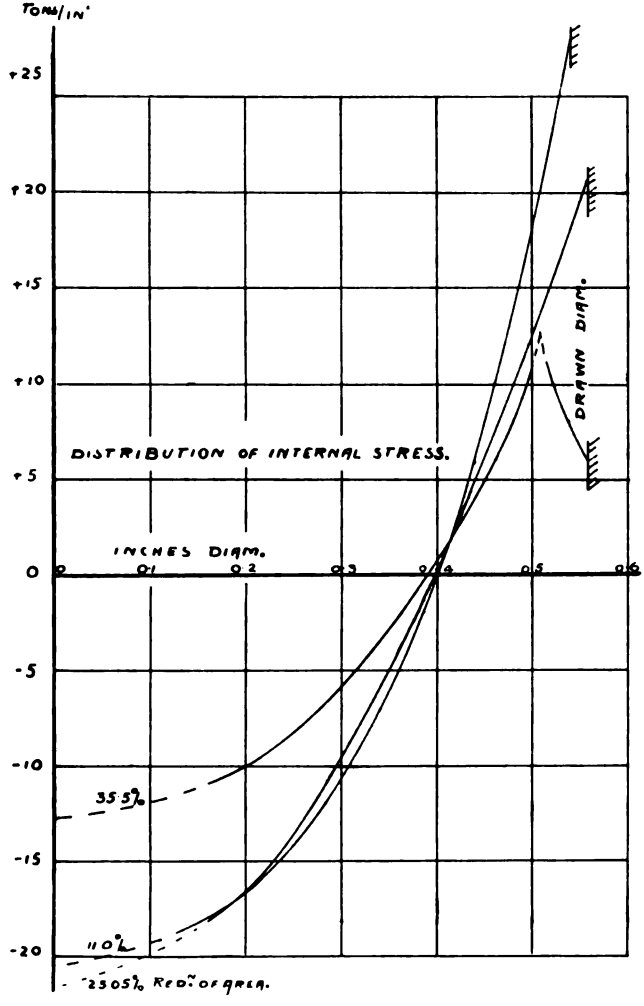

Fig. 6.

and this elastic recovery provides the stressing force. The material also offers a resistance to flow or deformation, and

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this resistance to recovery of its original form provides the reaction which constitutes the other partial aspect of the stress, and thus permits the internal stresses to develop.

The internal stress may, under certain conditions, develop until the value is reached at which slip or plastic flow would again supervene. The maximum internal stress is, therefore, in some respects an elastic limit for the material, since it determines the limit of elastic recovery of the material under the degree of cold work which has been applied to it.

It, therefore, seems reasonable to assume that, if excessive cold-work is done on a material, the slip lines will have developed to a greater extent, and will be less easily healed. Under such conditions elastic recovery must necessarily be less, and, if the foregoing explanation be accepted, the internal stress intensity must also be less.

The same explanation serves to account for the lower boundary stress with severe cold-working. The outer skin of the material has been subjected to greater punishment under the high die-pressures and friction drag, and it is, therefore, to be expected that its elastic properties have been impaired thereby. In Prof. Heyn's original paper, he noted that the stresses in a cold-drawn copper-zinc alloy were at a maximum some distance from the surface when tested five days after drawing, but that after having been rested for two years the maximum stress was found at the outer surface. This would appear to indicate that there had been some healing effect with time, and that the material had become more truly elastic. In the present tests, the bars were aged from 11 to 13 months before the machining tests were carried out. Several check tests were made close to the surface, by reducing the diameter by $\frac{1}{1000}$-inch steps, but such tests failed to reveal lower stresses at the outer skin in the case of the two more lightly-worked specimens. It is to be expected that a deep drawing steel would not show the phenomenon of reduced surface stress so readily as would a harder steel. An investigation at constant reduction of area carried out with a series of steels of different carbon content would, therefore, give interesting results.

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That lower internal stresses are obtained at higher reduction of area is also clear from some tests on arsenical copper tubes made by Messrs. Pinkerton and Tait.* Longitudinal stresses as estimated by the tongue method were:—

Reduction of area. Per cent.		Longitudinal stress. Tons /in.^{2}.
12	...	19·1
21	...	18·2
32	...	22·0
43	...	18·6
57	...	14·8
73	...	11·8

For the lower reductions of area the stress may be regarded as approximately constant within the degree of accuracy to be expected by the method, but the reduction of internal stress at the higher reductions is apparent.

The result is not in agreement with the data obtained by Mr. G. Masing† from tests on 70/30 cold-rolled brass rods. In those tests approximately the same stress was recorded at the outer surface for reduction of area of 20 and 40 per cent., but for a 60 per cent. reduction the skin stress was about double. The results obtained were very erratic; most bars showed small tensile stresses in the neighbourhood of the axis.

Approximate values of the skin stress when the bar has been turned down to different diameters may be obtained from equation (1) by estimating the mean reduction of stress, which, acting on the outer annulus, would cause the change of length actually observed to be due to the machining operation. The stress steps and the mean curves shown in Figs. 7, 8, and 9 may be regarded as giving some indications of the relief of stress due to machining, although the method is again liable to some irregularities and uncertainties. For more ready comparison, the mean curves have been superimposed in Fig. 10. They are also reproduced in graphs 16, 17, and 18, which show the collected results of the various tests on each set of bars. Further comment on the curves is reserved in the meantime.

* Journ. Inst. of Metals, 1926.

† Zeitschrift für Metallkunde, 1925.

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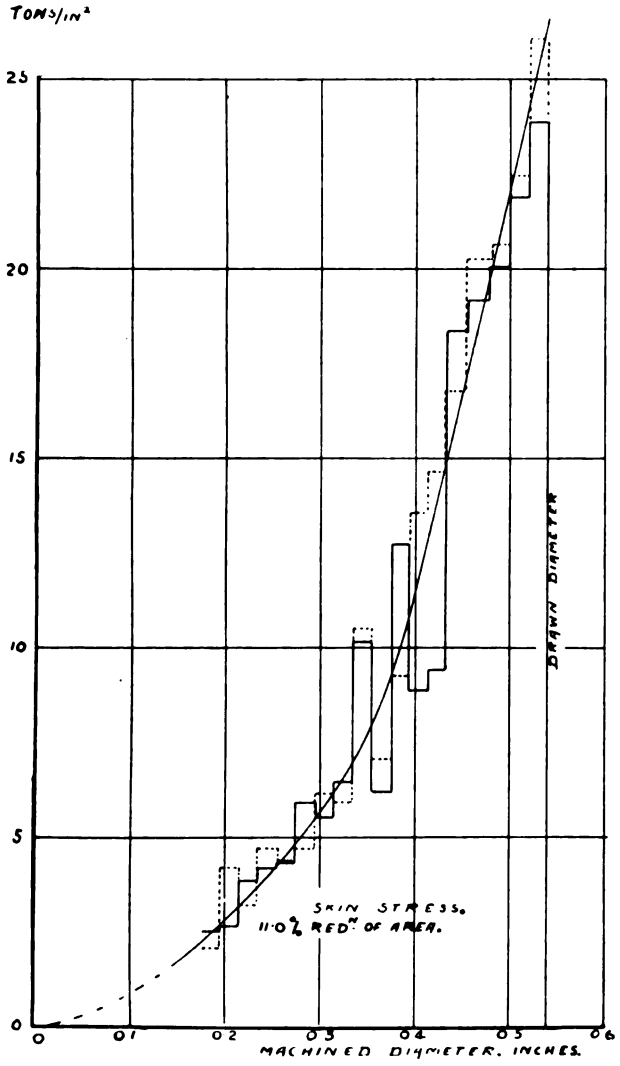

Fig. 7.

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Effects of Machining.

The effects of cold work on a material can probably be included in two main groups of phenomena:—

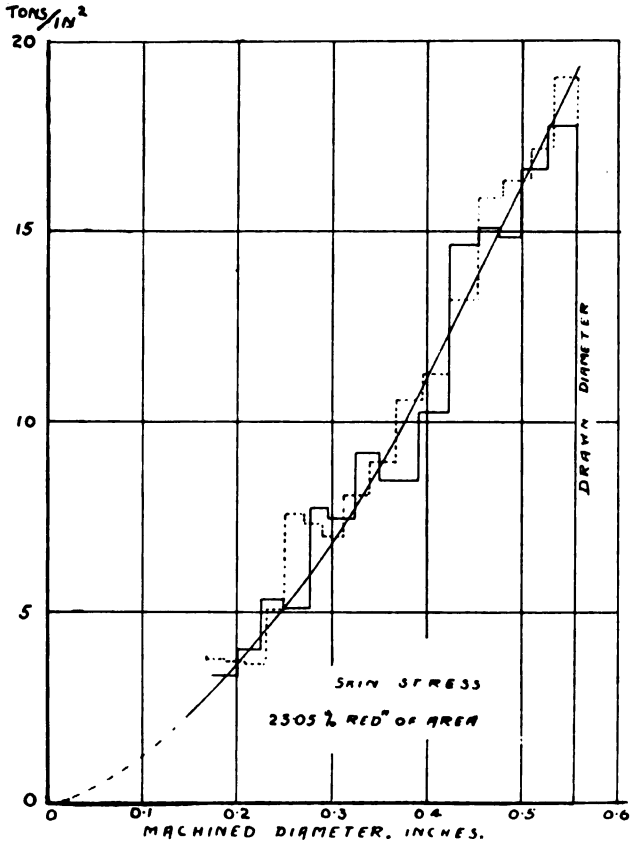

Fig. 8.

1. Primary, or intrinsic effects of cold work on modifying the properties of the material.

2. Secondary effects produced by the internal stresses which result from cold drawing.

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The intrinsic effects of cold drawing are not readily determined, but the effects of internal stresses, or, at least, the effects of the modification of internal stress consequent on machining, offer a ready field of investigation. The properties which are of most direct interest to the engineer are those revealed by the direct tensile test and by the Wöhler rotating

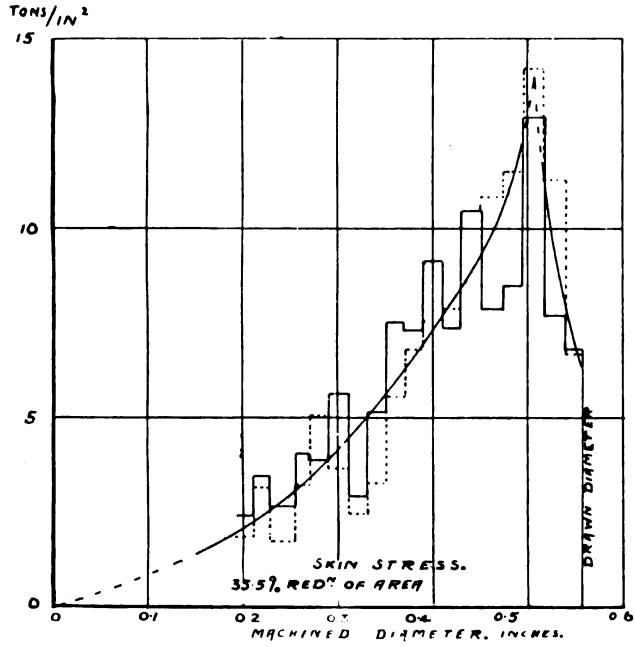

Fig. 9.

cantilever test. Accordingly a series of tests for each degree of cold working was arranged, using specimens which had been drawn to approximately the same diameter, and which were machined to different diameters.

Many investigators have emphasised the desirability of obtaining the complete history of a test piece up to the point of fracture, and not only a few isolated results obtained from a test. Such information is most conveniently obtained from

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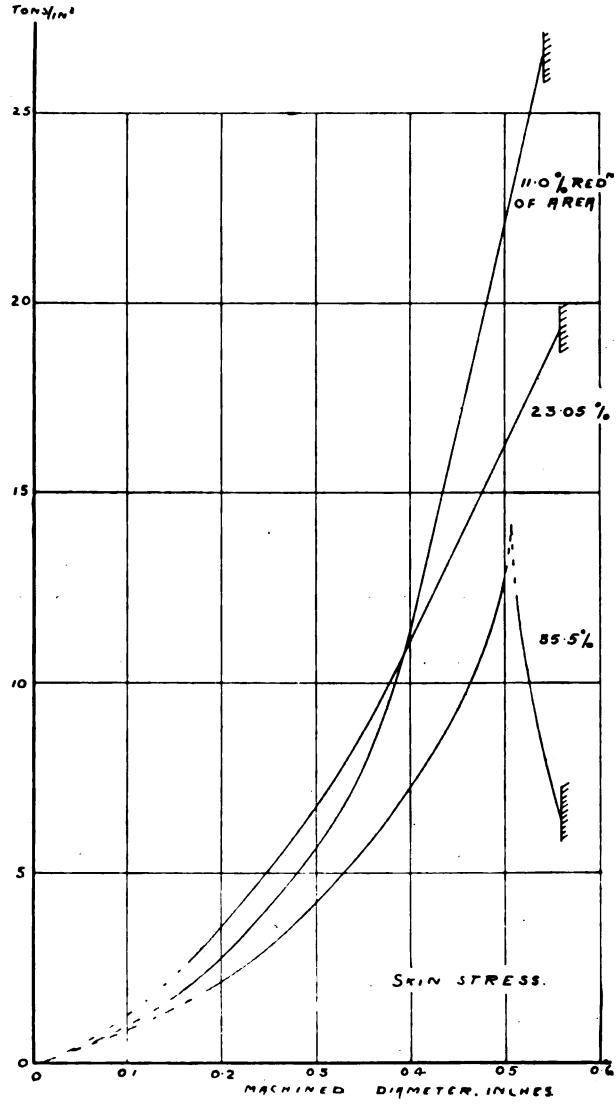

Fig. 10.

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an autographic record. In the present tests the autographic recorder was not used, but the extensometer was kept on until the specimen commenced to neck, or until the extension exceeded the range of the instrument. If rapid extension occurred, the end of the beam dropped on to a tension spring, which, by relieving the stress on the specimen, reduced the danger of damage to the extensometer due to a premature fracture.

With cold-worked specimens, which have no definite yield point, it is possible to obtain data with an extensometer test, and with the ordinary measurements of a normal tensile test, which permits of an approximate sketch being made of the stress-strain graph. The following observations were made:—

a. Modulus, or slope of the stress-strain graph.

b. Limit of proportionality.

c. Proof stress, taken as the stress required to produce 0·1 per cent. elongation; the value of 0·5 per cent. recommended for mild steel is too large for cold-worked materials, and it gives results which are, practically, those obtained by the breaking test.

d. Stress at which creep was first noted. This is a purely arbitrary figure, but it indicates that the form of the portion of the stress-strain graph for stresses higher than those recorded is perceptibly affected by time, or by the rate of loading. The figure recorded was obtained by the following procedure:—A known increment of load was applied, and the extensometer reading was noted and the reading booked. A check reading was then taken. When the check reading differed perceptibly from the original reading, the stress at which this occurred was noted as the 1st creep stress. This sluggishness of the strain in keeping pace with the increased stress was noted at loads below the proof stress.

e. Ultimate strength.

f. Percentage elongation on $4\sqrt{\text{area}}$. The percentage elongation was, when possible, divided approximately into local and general elongation. Specimens were generally

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sufficiently long to permit of a chain of gauge lengths being marked off along each; three such series were used, with the gauge points slightly staggered from each other to ensure that the elongation would be obtained with the point of fracture within the middle third of the length. The elongation on gauge points as far removed as possible from the point of fracture was taken as giving a rough indication of the general elongation, and thus locating a point on the stress-strain curve where the maximum strength was recorded.

g. Percentage reduction of area.

The tensile tests were made on a 10-ton Buckton machine. Most of the specimens were held in wedge grips, but those of smaller diameter were tested in screwed grips in order to reduce the length of the specimen, and thus reduce the chances of bending in the lathe or of irregular action of the wedges.

A Ewing extensometer, reading to $\frac{1}{2.5.0.0.0}$ inch, and by estimation to $\frac{1}{2.5.0.0.0}$ inch, was used on a four-inch gauge length.

Wöhler tests were carried out on a rotating cantilever machine made by Messrs. Amsler. Fig. 11 shows the form and dimensions of the test pieces used. The test sections were parallel for $\frac{1}{8}$ inch on the smaller specimens, and $\frac{3}{16}$ inch on the larger sections, and were well radiused out to the diameter of the bar. The grooves were machined out in a profiling lathe, and were roughly standardised. All tensile and fatigue specimens were finished with No. 0000 emery cloth to reduce scratch effects to a minimum. The researches of Thomas* and others into the effects of surface finish indicate that specimens so polished should, other effects being equal, be consistent to a high degree.

In investigating the endurance range, the object was to establish a practical endurance range based on at least 12×10^6 cycles. Solid specimens were used. In the earlier tests, runs of 6×10^6 cycles were used for rangefinding, and check tests were run to 12×10^6 cycles after the earlier tests had located

* Engineering, Oct., 1923.

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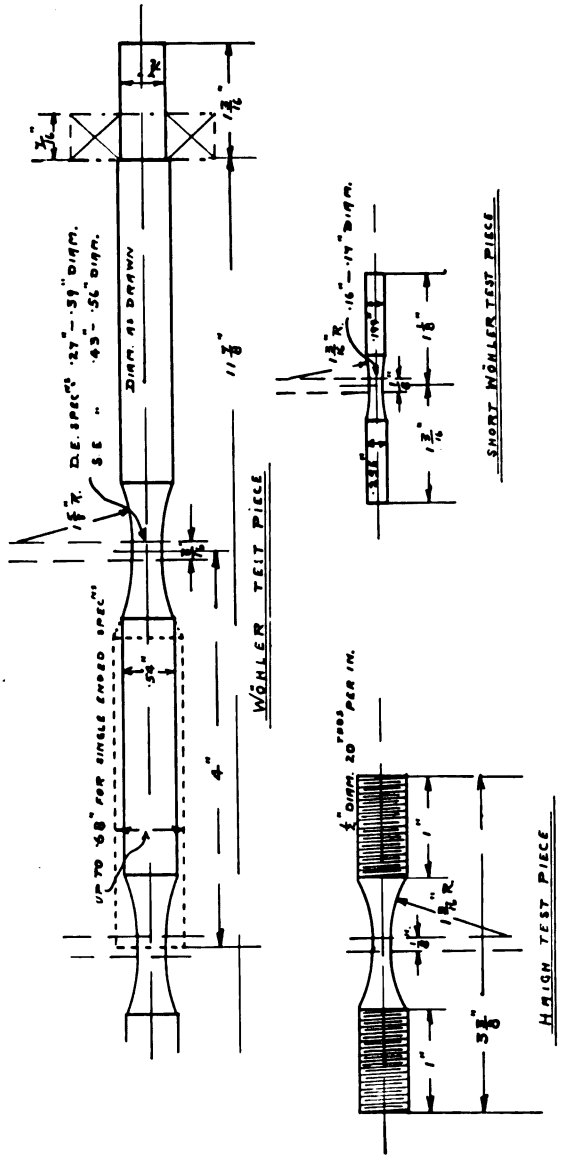

Fig. 11.

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approximately the limits between which the endurance range was to be expected. This practice was not very satisfactory with the Wöhler machine, and longer tests had to be used even for rangefinding. Short tests of 6×10^6 cycles were fairly satisfactory in the Haigh machine when reversed stress tests were being made, but they were quite misleading when high mean-stresses, especially compressive stresses, had been applied.

Typical endurance curves are shown in Figs. 12 and 13, and log S/N curves corresponding to Fig. 13 are shown in Fig. 14. The curves in Figs. 13 and 14 were obtained from specimens of approximately the same diameter, and made according to the diagram for the smaller specimen shown in Fig. 11. The curves in Fig. 13 are of the usual type, but they do suggest that the curve for the annealed material tends to become asymptotic to the endurance range at a lower number of cycles than is the case with the cold-drawn material. This fact, that, when subjected to stresses which exceed the safe range, cold-drawn material has a greater endurance, or a longer life, than has the annealed material, is commented upon by Mr. F. S. Merrils.* The log S/N curves show the change of slope which is generally taken as evidence that there is a definite endurance range which will give a practically indefinite life. The evidence for this indefinite life is not very convincing, so far as the cold-drawn material is concerned. This point will be referred to later when discussing the effect of mean stresses. The test results are submitted in all cases as endurance ranges for a life of 12×10^6 cycles. This is perhaps the shortest life which will give a really useful basis of comparison.

When testing Wöhler specimens of large diameter, considerable trouble was experienced due to specimens breaking just outside the collets, on the enlarged ends where the bending stress, assuming free cantilever conditions, was much lower than at the test section. The trouble was at first associated with the greater skin stress at the circumference, but this explanation was not entirely satisfactory. To obtain curves for

* Carnegie Scholarship Memoirs, 1924.

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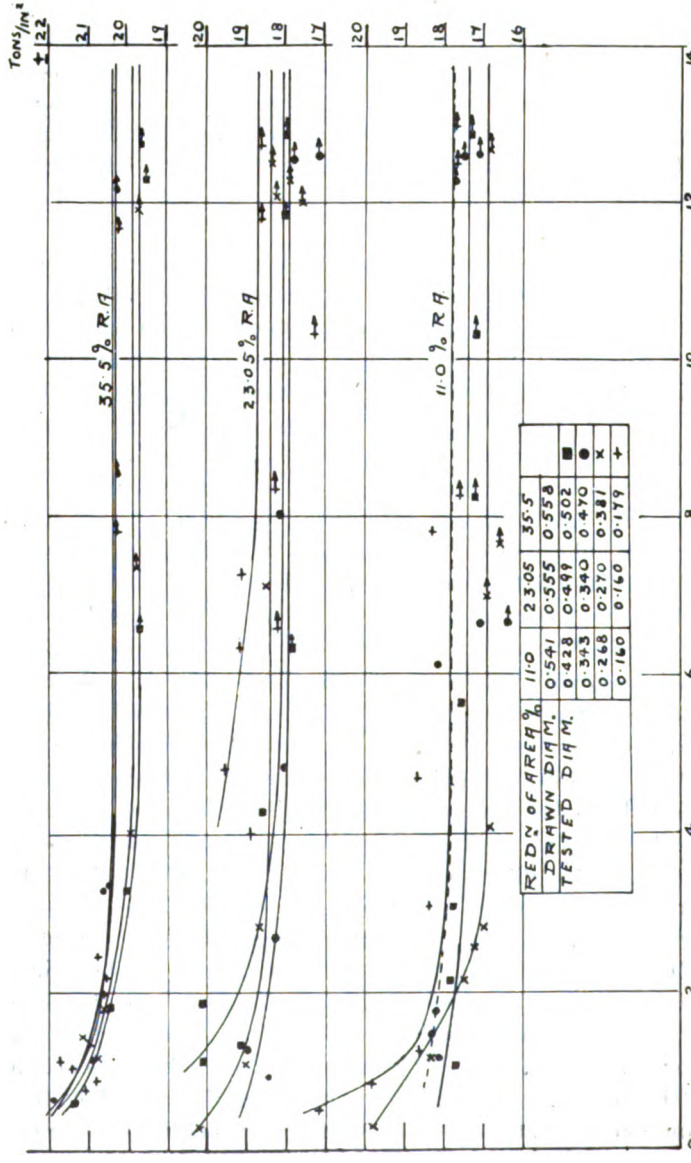

Fig. 12.

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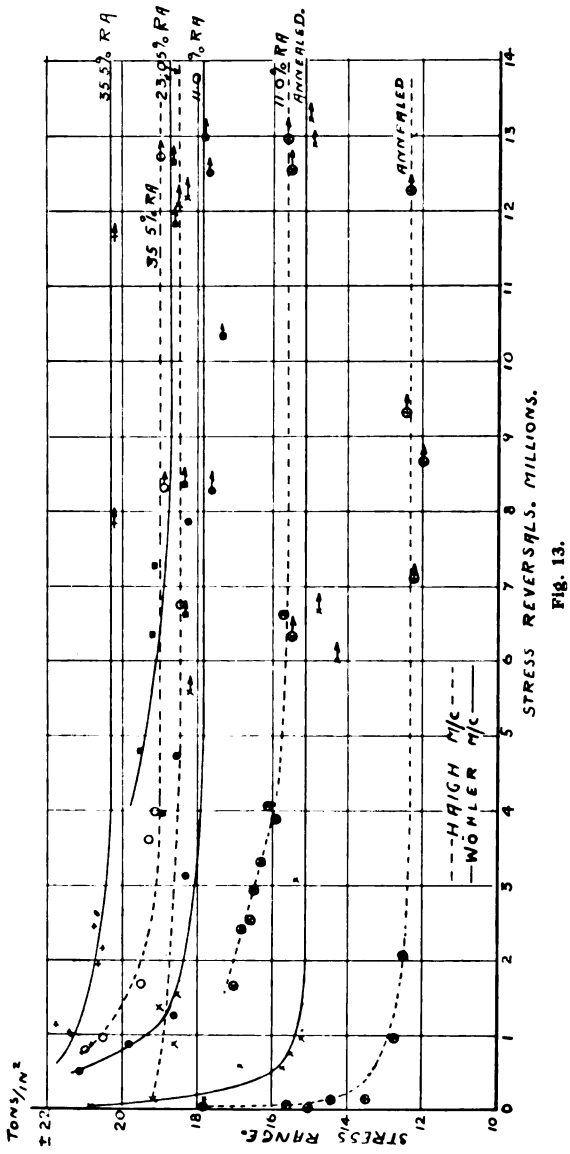

Fig. 13.

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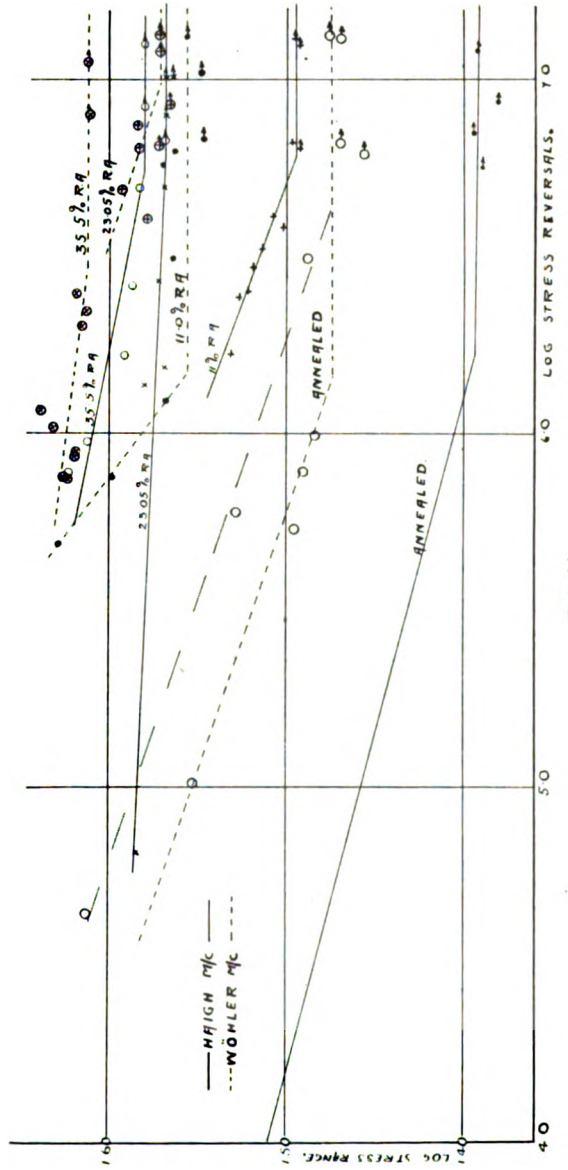

Fig. 14.

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Reduction of Area. Per cent.	Drawn Diameter. Inches.	Ultimate Strength. Tons/In.^{2}	Elongation on $4\sqrt{\text{Area}}$. Per cent.	Reduction of Area. Per cent.
Annealed	—	$32{\cdot}23^{+\cdot12}_{-\cdot05}$	$37{\cdot}59^{+\cdot54}_{-2\cdot94}$	$53{\cdot}64^{+\cdot92}_{-\cdot37}$
		about 20 per cent.		
11·00	·5410	$37{\cdot}51^{+\cdot96}_{-1\cdot36}$	$19{\cdot}40^{+1\cdot95}_{-1\cdot43}$	$51{\cdot}39^{+1\cdot43}_{-2\cdot01}$
		bout 1·75 per cent.		
	·5410	38·86	21·86	50·70
		38·84	20·05	51·17
		38·53	19·16	49·83
		38·39	21·44	48·00
		38·04	21·90	50·12

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the largest diameters possible, some specimens were drawn through the die for a sufficient length, and were then removed from the die so that the portion within the collets might be turned from a greatly enlarged butt of annealed stress-free material. Collets were made to fit the maximum possible diameter in each case. By this means it was possible to test to larger diameters, but trouble was still experienced due to fracture within the collets, and limiting diameters were soon

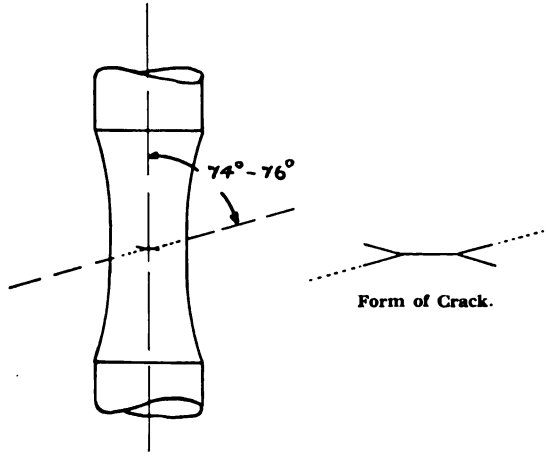

Fig. 15.

reached. With the larger specimens, the fracture tended to follow a more or less spiral path. Fractured specimens frequently showed cracks of the form indicated by the full lines, and the normal path of fracture appeared to be along the dotted lines, Fig. 15. First failure appeared to occur normally on a diametrical plane.

The results of the tensile tests are given in Table III, and of the Wöhler tests in Table IV.

NOTES TO TABLE IV.

Reduction of Area, 23 per cent.

Series with 0·39-inch diameter specimens. A somewhat

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TABLE IV.

WÖHLER TESTS.

Reduction of Area. Per cent.	Drawn Diameter. Inches.	Diameter at Test Section. Inches.	Reversal Limit. Tons In.^{2}	Ultimate Strength (from Graph). Tons In.^{2}	Wöhler Range (from Graph). Tons In.^{2}	Ratio. Range / Ultimate Strength.
Annealed	—	·3934	±15·7	32·24		0·974
		·1679	±15·1			0·936
11·00	·541	·4281	±17·4	38·4	±17·5	0·911
		·3906	±17·5			
		·3431	±17·8	Approximately constant.		
		·2684	±16·9			
		·1596	±17·8			
23·05	·555	·4987	±18·1	43·4	±17·8	·822
		·4703	±18·3	43·5	±17·9	·823
		·4376	±17·9	43·6	±18·0	·824
		·3907	±17·7	43·9	±18·1	·824
		·3404	±17·9	44·0	±18·2	·827
		·2701	±18·4	44·2	±18·4	·833
		·1603	±18·7	44·5	±18·6	·836
35·5	·558	·5568	Unable to obtain S/N curve. One specimen broke after 659,400 cycles at ±20·0 tons/in.^{2}			
		·5018	±19·8	45·9	±20·0	·872
		·4700	±20·4	46·0	±20·0	·870
		·3810	±19·7	46·4	±20·0	·862
		·2600	±20·0	46·9	±20·0	·853
		·1791	±20·3	47·2	±20·1	·852

unsatisfactory curve was obtained after 12 tests, seven of which broke in the collets, where the free cantilever stress-range was of the order of ± 8·5 tons/in^2. The diameter in the collets was about ·544 inch, with the material only just trued

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up. The tests on larger diameters were carried out on single-ended specimens with large annealed butts.

Diameter 0·4987 inch. Two specimens broke in the collets and also at the neck. The free cantilever stress at the fracture in the collets was about $\pm$ 13·7 tons/in^2, and the calculated stress at the fracture at the test section was about $\pm$ 18·2 tons/in^2. The specimens withstood about 5×10^6 cycles. Butt diameter, 0·619 inch. All attempts to test larger specimens failed.

Reduction of Area, 35·5 per cent.

Attempts were made to test specimens with the die marks polished out and practically no machine work done on the test section. The butt diameter was about 0·68 inch. Tests were discontinued after the following results had been obtained:—

Cycles.		Estimated test stress. Tons/In.^{2}	Remarks.
459,000	$\pm$	21·5	Broke at extreme edge of the annealed portion at edge of collets where the approximate free cantilever stress was about $\pm$ 13·8 tons/in.^{2}
659,400	$\pm$	20	Broke at test section.
737,300	$\pm$	19·5	Broke on annealed portion under an estimated stress range of $\pm$ 13·36 tons/in.^{2}

The low values obtained for the endurance range on the annealed butts indicate that there was a "grip" effect which reduced the range by about $\pm$ 2 tons/in^2. The cause of this was not ascertained. The values obtained in Table IV show no very great difference in the endurance ranges for diameters for which a complete S/N curve was obtained, but it is clear that had an S/N curve been obtained at, or near, full diameter, the endurance range would have been considerably lower; the single reading of $\pm$ 20 tons for 659×10^3 cycles lies well below the S/N curves obtained with smaller diameters.

This is consistent with the results obtained from the investigation into the distribution of internal stresses. If, as has been suggested, the lower skin stress shown in Fig. 9 is due to imperfect elastic recovery consequent on unduly severe surface working, low skin stresses and low endurance ranges

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should be associated, and a higher endurance range might be expected when the bars are machined down to the diameter which corresponds to the peak of the internal stress intensity curve in Fig. 9; that is, to a diameter rather less than 0·51 inch. The only specimen successfully tested at a larger diameter has obviously a lower endurance range, although the magnitude of the range could not be ascertained.

Table III permits of comparison being drawn between annealed and cold-drawn specimens, and between cold-drawn, as drawn, and cold-drawn machined specimens.

Figs. 6 and 10 indicate that internal stresses appear to be very high, and that the relief of skin stress due to machining is considerable. It is naturally expected, therefore, that this internal stress and relief of stress has considerable influence on test results. It seems to be obvious that, if a material has severe internal stresses, the addition of a relatively small additional load should cause some slip to take place in those crystals whose slip planes are most unfavourably inclined to the direction of the applied stress. It is, therefore, to be expected that an internally-stressed material should show a lowered limit of proportionality, and that, as stresses are relieved by heat treatment, machining, or by the application of pulsating loads, etc., the limit of proportionality should increase.

The graphs, Figs. 16, 17, and 18, show, on the whole, a slight tendency for the limit of proportionality to increase as the specimens are reduced in diameter, but the results are not convincing, since the variations between consecutive readings are, in some cases, greater than the general rise over the complete range of the experiments. The reason for this is to be found in the nature of the stress-strain curves and in the methods of testing. Examination of the stress-strain curves plotted on a large scale indicated that the graphs were in all cases flat curves which appeared to curve gradually from the origin. The modulus lines were drawn as mean straight lines lying evenly among the readings obtained for low stresses. The lines are, therefore, to be regarded as giving chord moduli for

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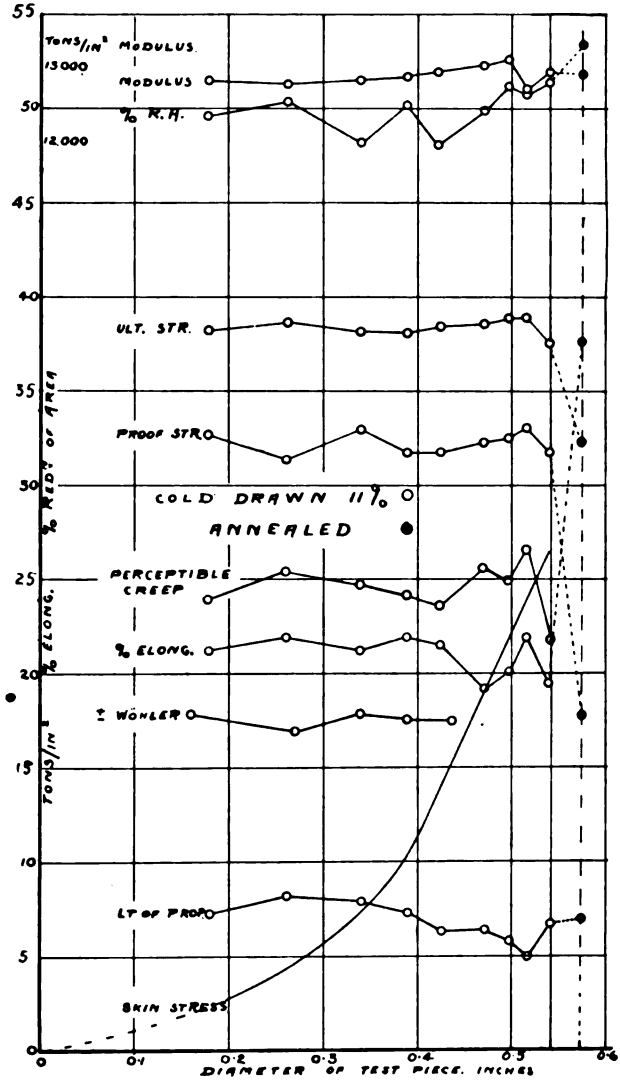

Fig. 16.

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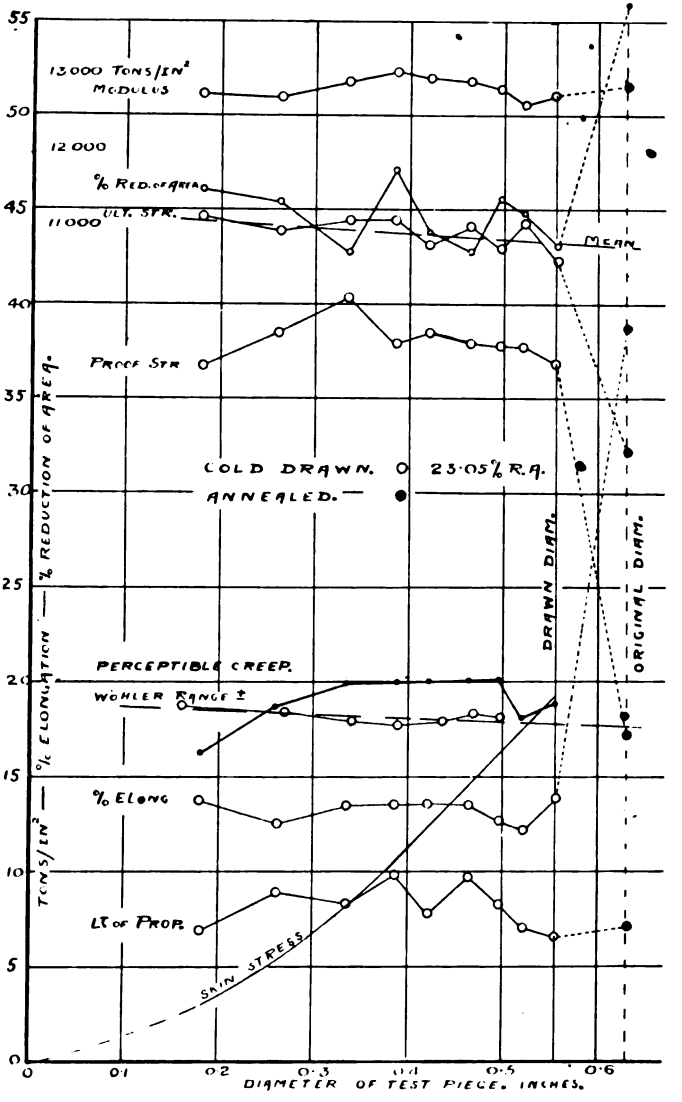

Fig. 17.

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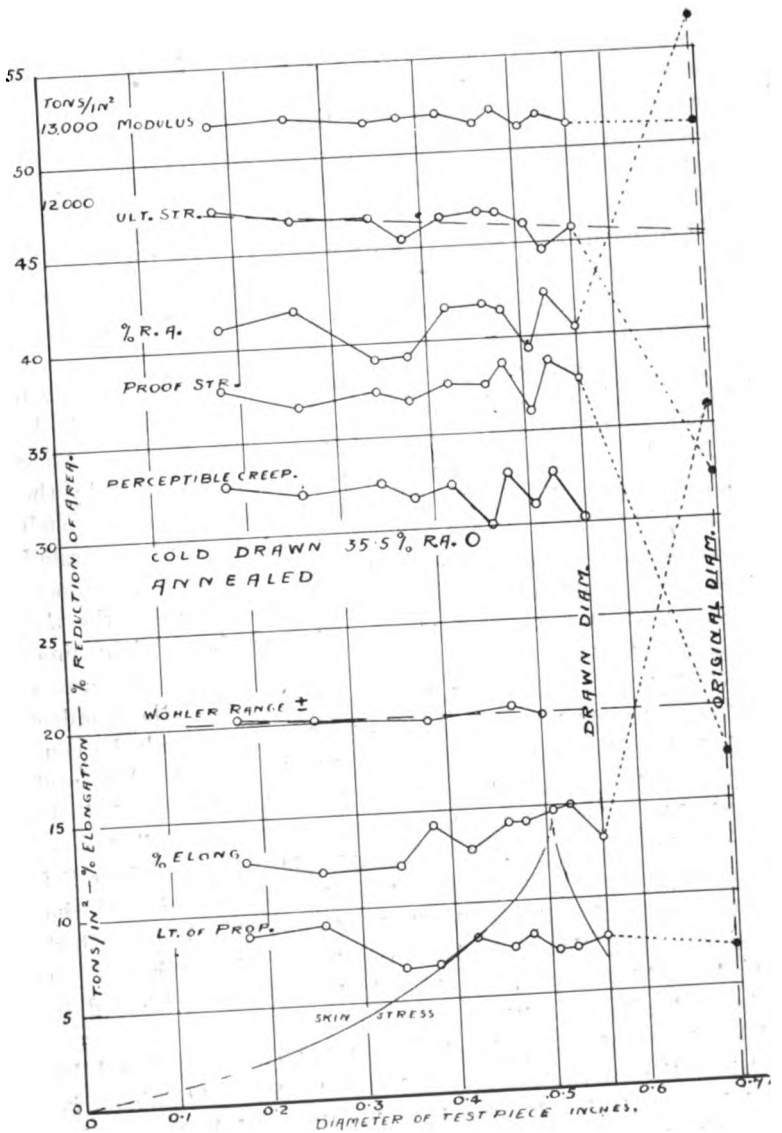

Fig. 18.

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a very small chord of the stress-strain graph, rather than as an indication of the existence of a straight line portion of the diagram. It seems to be much more probable that there is no really straight line portion, and, therefore, no limit of proportionality in the strict sense, and the high internal-stresses obtained at the larger diameters indicate that it is improbable that any additional stress whatsoever would be required to cause a departure from true proportionality. At the best, the limit of proportionality is so low that the effect of internal stress on lowering the value cannot be detected by ordinary extensometer methods.

The extensometer measures the mean extension over a given length, and a much finer method of measurement would be required to detect the commencement of slip under increasing stress. The total extension of a specimen as recorded by the extensometer is due to the summation of several effects, such as elastic deformation of the space lattice, slip, or to the relief or modification of the internal stresses. The limit of proportionality as obtained from a stress-strain diagram marks the point where the stress-strain curve leaves the straight line. Departure is, in many cases, so very gradual that the stress at which it occurs is not definite, and in view of the number of factors to which extension may be due, it can only be concluded that the limit of proportionality is not a fundamental property of a material, and its determination is of little practical interest to the engineer. Comparatively small stresses or pulsating stresses may have considerable effect on the relief of internal stresses, and may thus change the value of the limit of proportionality. The limit of proportionality of a test specimen may, therefore, be very different from that of an actual machine part in service which has been subjected to different loading conditions.

The limits of proportionality as tabulated were found by plotting the stress-strain graph, and thus obtaining the modulus. Calculated extensions for the modulus, assuming a straight-line law, were obtained for each load applied, and the differences between calculated and measured extensions

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were plotted against stress. The departure of the curve from the line of zero difference indicated the limit of proportionality recorded.

Ultimate strength and, to a lesser extent, proof stress are not likely to be so greatly affected by the internal stresses. When the stressed material reaches the somewhat plastic state at which cold flow commences, internal stresses are released, and, therefore, less variation in the plastic than in the elastic phenomena would be expected. The fact that the proof stress lies higher than the somewhat arbitrary figure for the first creep, indicates that the material is slipping, or flowing, although somewhat reluctantly, at stresses lower than the proof stress, and that, therefore, the plastic condition has already supervened.

The graphs show a slight gain in strength as the bar is turned down, and as a general rule the strength of the material, as drawn, appears to be less than the strength after machining. This appears to be reasonable, as the surface layers, especially after heavy drawing, are more likely to show unhealed slip lines or cracks where the drag of the metal under the heavy die-pressures has been most marked. This condition of lowered ultimate strength would be consistent with the lower internal stresses recorded in Table II, since the material which had its elasticity and its structure impaired by excessive cold-work would naturally fail at lower loads. It would, therefore, be expected that the most heavily worked specimens (35·5 per cent. reduction of area) would show the greatest increase of strength due to the removal of the surface layers. The gain of strength for the material cold-worked to this extent differs by a fraction of a ton only from the gain shown by the moderately cold-worked material; the lightly cold-worked material shows no increase of strength.

Percentage elongation appears to be practically unaffected for the two lighter reductions of area, but to decrease slightly as the diameter of the more severely cold-worked specimen is reduced by machining. Percentage reduction of area appears to show no decided effects of machining; any slight variations

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in trend are completely overshadowed by the variations between the readings. Percentage elongations and reductions of area are not usually so consistent as the other properties; they are much more sensitive to the conditions at the instant of fracture, and a full-cup fracture may be expected to give greater values than the half-cup or other forms of fracture.

The test results on the whole fail, therefore, to reveal any decided effects of machining. Consequently, it may be assumed that cold-drawn material may be tested after machining to almost any diameter, and that the tensile-test results may be accepted as giving values which are reasonably characteristic for the material, and which will certainly lie well within the limits permitted by normal specifications.

Table IV and graphs 16, 17, and 18 show that the Wöhler endurance limit is also reasonably independent of diameter of test piece, and that for all diameters it bears nearly a constant ratio to the ultimate strength; the ratios for the cold-drawn material appear to be somewhat lower than might normally be expected.

Typical Wöhler curves are shown in Fig. 12. The graphs show casual variations rather than results which trend in a definite direction. It may, therefore, be regarded as reasonably satisfactory if the mean values of the Wöhler reversal ranges are given as indicating the effect of cold work on the reversal range for any specified amount of cold work. Such values are incorporated in Table V. Fig. 13 shows endurance curves for different amounts of cold work when tested on approximately equal diameter. The graphs show clearly the increase in the endurance range brought about by cold work.

Fig. 19 summarises the effects of cold drawing, and a few comments are necessary. The figures are obtained by averaging all test results, irrespective of diameter of test piece.

The modulus of elasticity in tension is unchanged.

The limit of proportionality appears to increase slightly with increased severity of cold working. This statement is subject to the criticism already mentioned that the modulus is really a chord modulus, and, as pointed out in the paper read to this

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Institution in 1925, increased severity of cold work causes the stress-strain curve to become more nearly straight, not owing

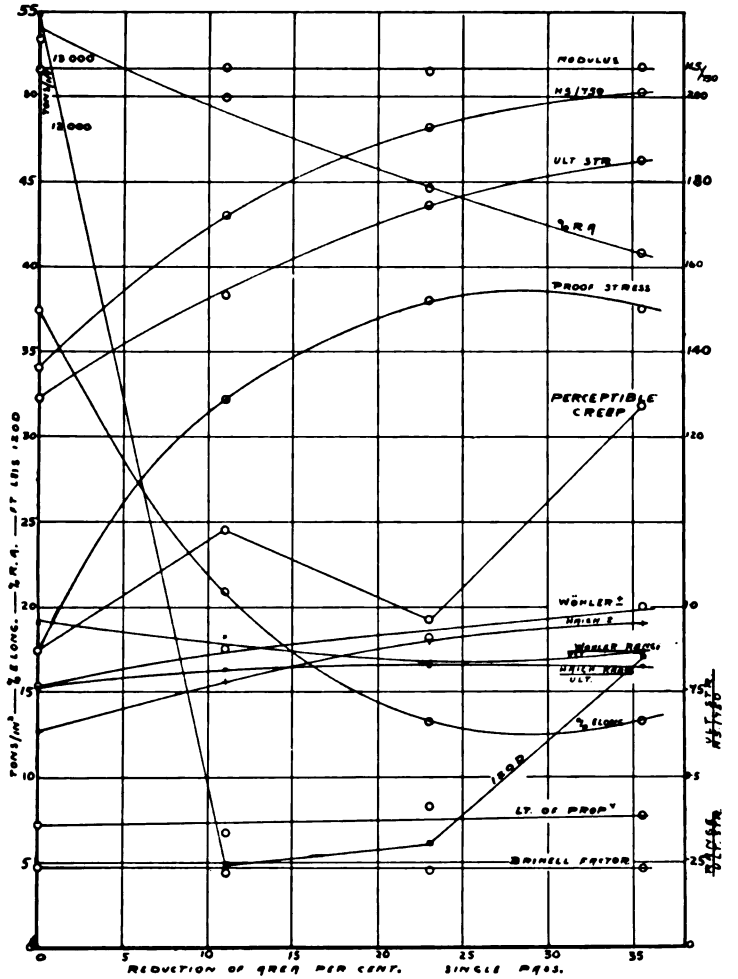

Fig. 19.

to more elastic behaviour of the material, but rather to the hardening effect diminishing the total strain, and, therefore,

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Table V.

Mean Values Irrespective of Diameters of Test Specimens.

Material.	Reduction of Area in Drawing. Per cent.	Modulus. Tons/In.^{2}	Limit of Proportionality. Tons/In.^{2}	Proof Stress. Tons/In.^{2}	Ultimate Strength. Tons/In.^{2}	Elongation on $4\sqrt{\text{Area}}$. Per cent.	Reduction of Area. Per cent.	Wöhler Range. Tons/In.^{2}	Ratio. $\frac{\text{W.R.}}{\text{Ult.}}$	Direct Stress Range. Tons/In.^{2}	Ratio. $\frac{\text{D.S.R.}}{\text{Ult.}}$	Izod. Ft.-Lbs.	Brinell $\frac{\text{H5.}}{750/15}$	Brinell Factor. $\frac{\text{Ult.}}{\text{H5.}}$
Annealed		12,880	7·27	17·43	32·34	37·41	53·38	±15·4	·955	±12·35	·766	54·64	136·1	·2369
Cold drawn	11·00	12,930	6·70	32·19	38·34	20·89	49·92	±17·5	·911	±15·6	·814	4·98	174·2	·2203
Cold drawn	23·05	12,870	8·25	38·02	43·61	13·21	44·59	±18·2	·827	±18·0	·825	6·12	192·8	·2268
Cold drawn	35·50	12,930	7·74	37·51	46·27	13·25	40·79	±20·0	·862	±19·0	·823	17·02	201·0	·2302

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rendering more difficult the determination of the point of departure of the curve from the straight-line relationship.

Proof Stress. The value obtained with 35·5 per cent. reduction of area is abnormally low; the proof stress-strain graph normally approaches more closely to the ultimate strength curve as the severity of the cold work increases.

Ultimate strength increases with increased amount of cold work.

TABLE VI.

DETAILS OF IZOD TESTS. CIRCULAR SPECIMEN, 0·45 INCH DIAMETER.

Annealed.		Cold Drawn. Reduction of Area.					
		11·0 per cent.		23·05 per cent.		35·5 per cent.	
68·0		8·6					
51·0	59·25	5·3	4·98				
71·0	Mean	3·0	Mean				
47·0		3·0					
37·0				6·0			
42·7	52·42			7·6	6·12		
70·3	Mean			9·0	Mean		
59·7				5·0			
				3·0			
59·8						8·8	
47·8						15·5	17·02
46·2	52·74					20·2	Mean
60·6	Mean					23·6	
49·3							

54·64 overall average.

Ductility. This normally decreases with increased amount of cold work. Percentage reduction of area diminishes with increased amount of cold work, but percentage elongation shows a slight increase at 35·5 per cent. reduction of area in drawing. This increased value is in agreement with the increased extension in the extensometer test, and with the reduction in proof stress consequent on this.

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Izod. The Izod value reaches a minimum and then increases again. This is in agreement with results formerly obtained and with results obtained by Mr. A. T. Adam.* The figures are given in Table VI.

Fatigue. The fatigue tests show rather curious results. The Wöhler range appears to bear an almost straight-line relationship to the percentage reduction of area, but the ratio $\frac{W}{U}$ decreases to a minimum and then increases again. The Haigh values, on the other hand, increase according to the ordinates to a smooth curve, but the ratio $\frac{H}{U}$ appears to reach a turning value and to diminish thereafter. The four points obtained are, of course, insufficient to permit of any definite conclusions being drawn when the variations obtained are so small as those indicated in the graph. Further experiments designed to obtain a series of points are being undertaken.

The figures in Table V show that the Wöhler reversal limit for the annealed steel exceeds the Haigh limit by 24·2 per cent. This is in substantial agreement with the results obtained by Messrs. H. J. Gough and H. S. Tapsell.† Those investigators found that the Wöhler range exceeded the Haigh range by 18 per cent. for a 0·13 per cent. carbon steel, and by 26 per cent. for a 0·33 per cent. carbon steel. It is interesting to note how the excess value changes due to cold-drawing. Thus:—

Per cent.						Per cent.
11	R.A. gives an excess of	Wöhler	over	Haigh	ranges of	12·17
23	,,	,,	,,	,,	,,	1·11
35·5	,,	,,	,,	,,	,,	5·27

Effects of Reversed Direct Stresses and of Initial Mean Stress by Tests on the Haigh Machine.

The chief object of the tests on the Haigh machine was to investigate the effect of superimposing a steady initial stress

* Wire Drawing and the Cold Working of Steel, 1925.

† Aero. Research Committee, Reports and Memoranda No. 1012, 1926.

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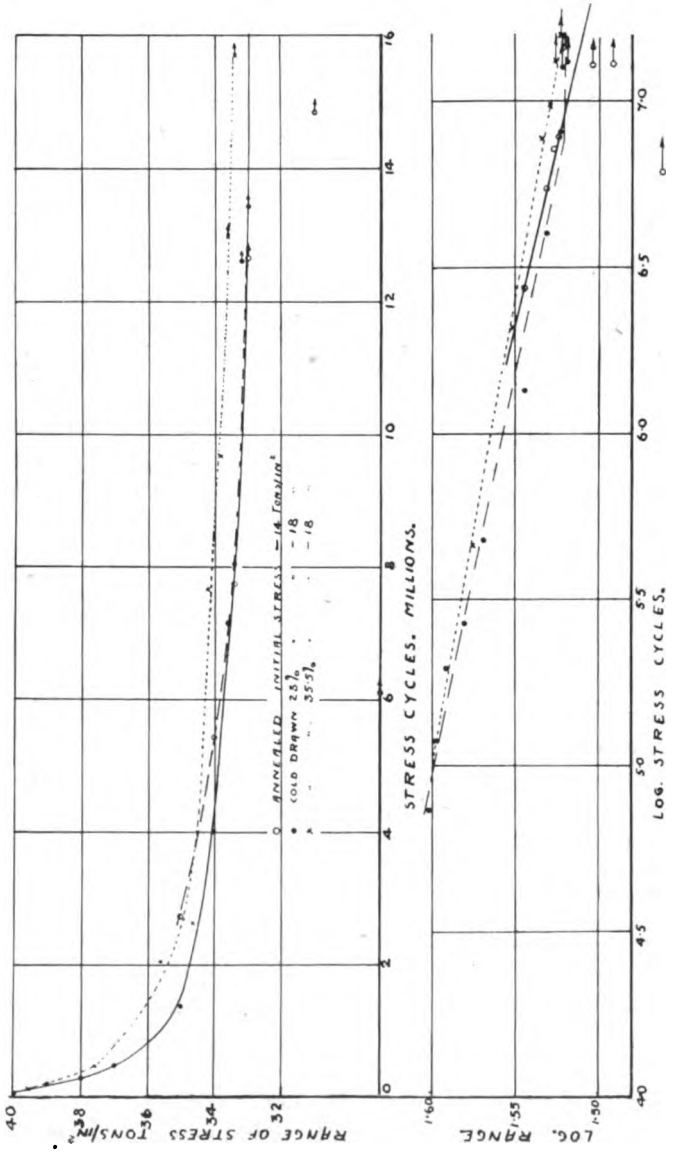

Fig. 20.

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on the pulsating stress and on the internal stress of the material, and to determine the relationship between the initial steady stress and the endurance range.

The S/N curves alone convey little information, and may be very misleading. When high mean-stresses are used creep occurs, and this continues at a decreasing rate with time, if the specimen is going to stand up to the test, but it accelerates greatly immediately before fracture. Fig. 20 shows typical S/N curves at high mean compressive-stresses with the corresponding logarithmic curves. The S/N curves suggest that under high mean-stresses longer tests are necessary to establish the asymptote to the curve, but the logarithmic lines show clearly that, even with runs up to 16×10^6 cycles, there is no evidence of a definite endurance range for an indefinite number of cycles. Creep curves, Figs. 26-31, show that creep has not finally ceased at the end of the tests, and indicate that failure with longer runs is extremely probable. It is, therefore, again emphasised that the figures given for the endurance range are merely those corresponding to a life of 12×10^6 cycles, and are, therefore, comparative among themselves. The values obtained are given in Table VII.

The results are plotted in several ways. Fig. 21 shows maximum and minimum stresses, and by intercept, the endurance range, plotted on a base of mean stress. The curves show clearly the effects of cold drawing on the maximum stresses which can be borne. Fig. 22 shows the ranges of stress only plotted on a base of mean stress, and it indicates the relationship between the experimental ranges and those indicated by Gerber's parabolic law. Fig. 23 shows the endurance ranges and mean stresses plotted as fractions of the ultimate tensile strength. This graph indicates that the cold-drawn material has not only a higher endurance range, but that it develops a greater fraction of its ultimate tensile strength. The results are rather curious, and are contrary to the results obtained on the Wöhler machine, in which the annealed material developed a greater fraction of the ultimate strength than did the cold-drawn material.

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s).

Condition.	Mean Tor	Mean / Ultimate Tension.	Maximum Stress / Reversal Stress.	Minimum Stress / Maximum Stress.
Annealed	-	0	1·000	−1·000
	-	+·186	1·442	−0·326
	-	+·310	1·725	−0·061
	-	+·434	1·928	+0·176
	-	+·558	2·138	+0·364
	-	+·713	2·345	+0·589
	-	−·186	1·685	− ·423
	-	−·310	2·097	− ·228
	-	−·434	2·470	− ·082
Cold Drawn 11 per cent. Reduction of Area.	+	0	1·000	−1·000
	+	+·156	1·378	−0·442
	+	+·313	1·718	−0·112
	+	+·469	2·032	+0·136
	+	+·626	2·238	+0·375
	+	+·730	2·314	+0·551
	+	+·834	2·359	+0·739
	−	−·156	1·391	− ·447
	−	−·313	1·788	− ·140
	−	−·469	2·180	− ·059
Cold Drawn 23·05 per cent. Reduction of Area.	+	0	1·000	−1·000
	+	+·138	1·314	−0·493
	+	+·275	1·564	−0·147
	+	+·413	1·839	−0·088
	+	+·550	2·019	+0·321
	+	+·688	2·278	+0·463
	+	+·757	2·295	+0·598
	+	+·825	2·350	+0·702
	−	−·138	1·383	− ·518
	−	−·275	1·739	− ·233
	−	−·413	1·917	+ ·043
Cold Drawn 35·5 per cent. Reduction of Area.	+	0	1·000	−1·000
	+	+·130	1·297	−0·513
	+	+·259	1·576	−0·199
	+	+·389	1·842	+0·028
	+	+·519	2·091	+0·208
	+	+·648	2·295	+0·376
	+	+·778	2·368	+0·600
	−	−·130	1·205	− ·516
	−	−·259	1·679	− ·248
	−	−·389	1·826	+ ·037

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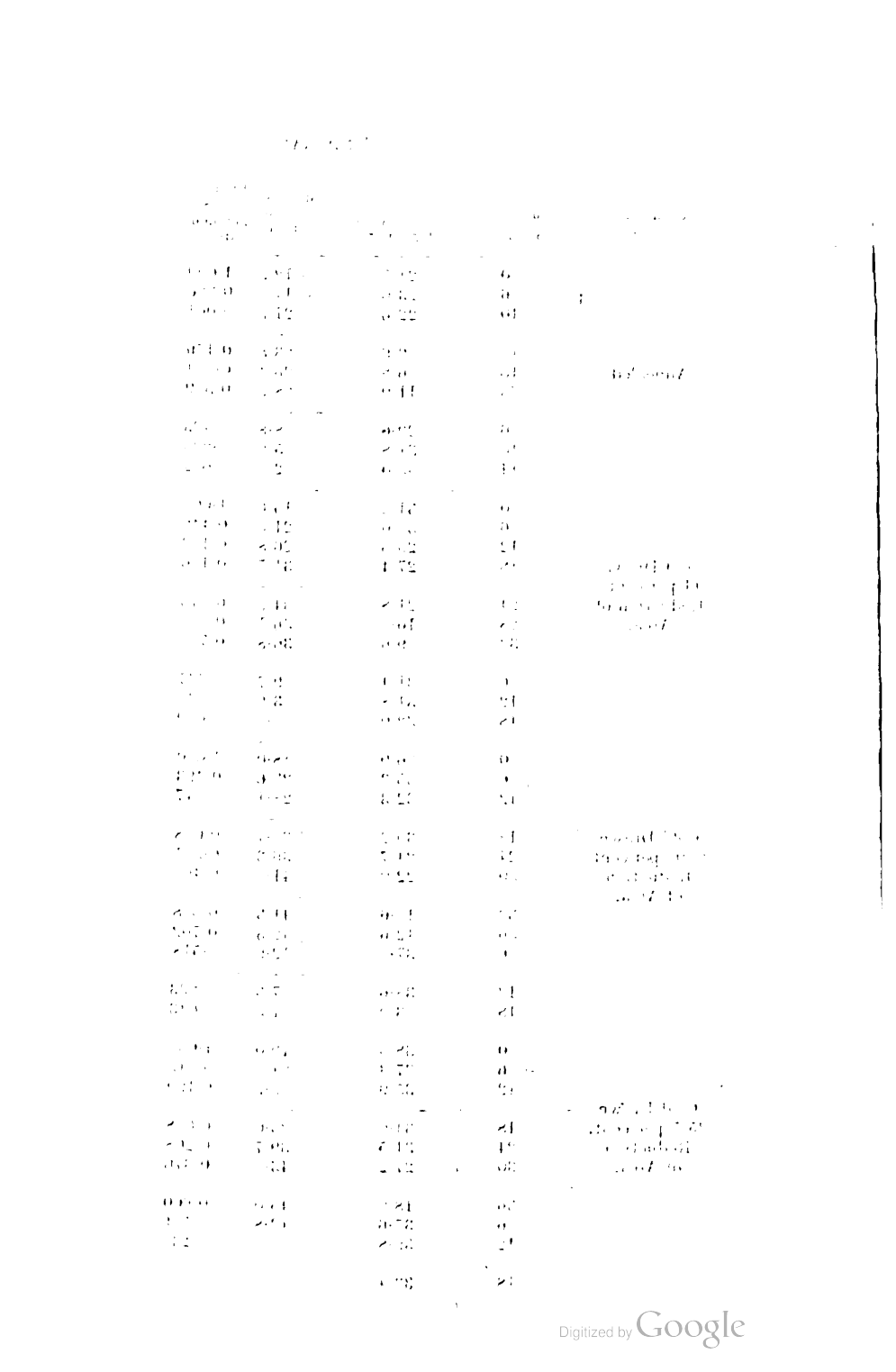

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Table VIII.

							(Break Observed).						
+28	16·2	12	+2683	12·240	+ 48		U.	39·20	47·79	+0·86	−2·13	+2·22	− 4·27
	16·0	10	+2591	6·432	+ 27		U.	40·24	44·60	+1·90	−5·32	+4·90	−10·64
	15·6	10	+2534	6·036	+ 26		U.	39·47	45·39	+1·13	−4·53	+2·91	− 9·07
	15·0	8	+2978	7·834			U.	40·95	44·70	+2·61	−5·22	+6·73	−10·43
+32	10·0	10	+2522	0·096	+1618	−48·29	B.						
	10·0	8	+2698	0·174	+1591		B.						
	9·8	10	+2857	0·120	+1458	−49·08	B.						
	9·8	6	+2515	0·480	+2127	−46·89	B.						
	9·8	4	+2155	18·380	+ 29		U.	39·85	46·07	+1·51	−2·85	+3·89	− 5·70
	9·8	6	+2623	13·200	+ 33		U.	41·25	43·34	+2·91	−6·58	+7·50	−13·60
− 6	31·8	6	−1330	4·762	− 488	+ 9·77	B.						
	31·6	10	−1274	18·290	− 40		U.						
	31·6	18	−1366	3·804	− 149		B.						
	31·4	14	− 981	8·214	− 116	+ 1·97	U.	38·78	48·76	+0·44	−1·16	+1·13	− 2·32
	31·2	8	−1120	9·474	− 72	+ 1·87	U.	39·96	47·63	+1·62	−2·29	+4·18	− 4·68
	30·5	12	−1109	7·186	− 21	+ 1·82	U.	39·33	48·48	+0·99	−1·44	+2·55	− 2·88
−12	32·0	10	−1544	9·702	− 816	+14·35	B.						
	31·8	8	−1497	12·664	− 537	+ 7·26	U.	43·63	45·52	+5·29	−4·40	+13·61	− 8·81
	31·0	8	−1409	12·682	− 497	+ 5·06	U.	40·32	46·49	+1·98	−3·43	+ 5·10	− 6·87
−18	32·8	12	−1930	1·062	− 830	+17·90	B.						
	32·4	8	−1852	12·946	− 825	+ 9·86	U.	40·78	44·55	+2·44	−5·37	+6·29	−10·74
	32·0	12	−1969	12·622	− 765	+10·85	U.						
	30·0	14	−1883	8·854	− 339	+ 8·90	U.	39·55	46·62	+1·21	−3·30	+3·12	− 6·61

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TABLE XIII.

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The results indicated in Figs. 21, 22, and 23 require some qualification. The graphs are conventional; that is, the results are discussed with reference to the condition of the material before test; this is the normal procedure. Table VIII shows

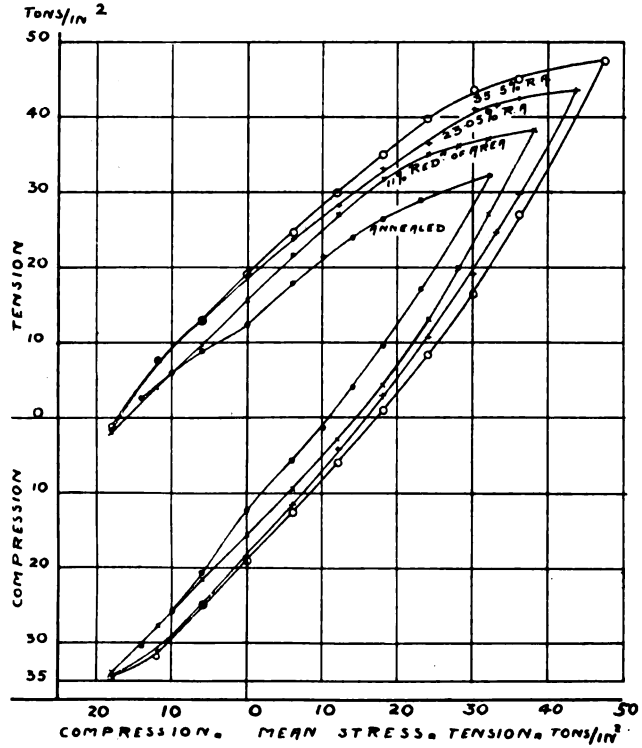

Fig. 21.

that, due to creep, final conditions are very different from the initial conditions, and that the annealed material may be finally cold-worked to the extent of about 13 per cent. after a test of 12×10^6 cycles; also that the cold-drawn material may be further cold-worked to a considerable extent by cold stretching or cold compressing while under the applied fluctuating stresses. The extent of the cold working under the pulsating stresses is by no means negligible.

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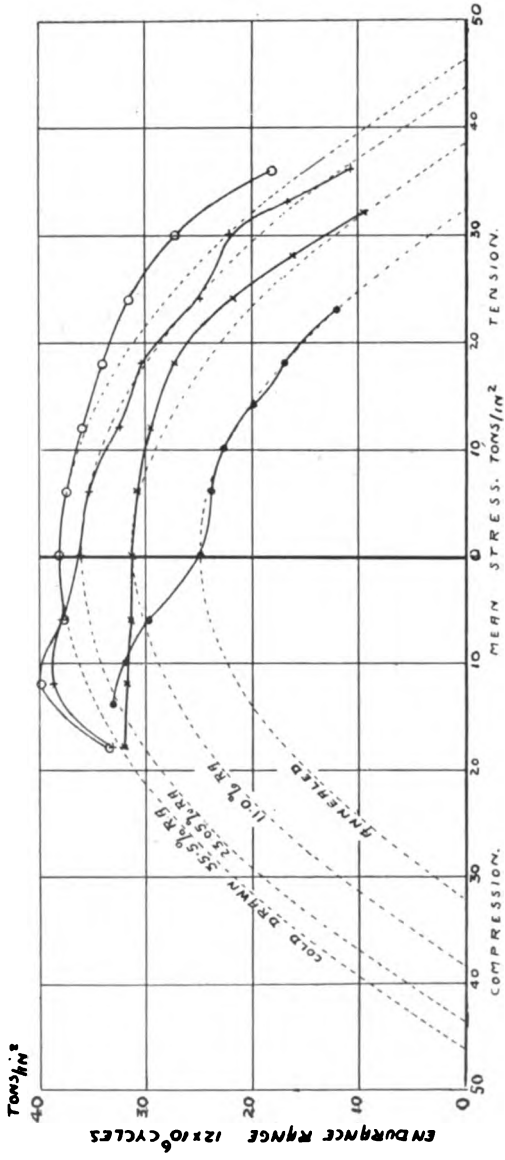

Fig. 22.

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The effects of change of area alone are considerable. For example, a specimen of the annealed material was subjected to a compressive stress of -14 tons/in^2 and a range of 33 tons/in^2. After $12{\cdot}628 \times 10^6$ cycles, the specimen had increased in area by 12·84 per cent. This change of area alone reduces

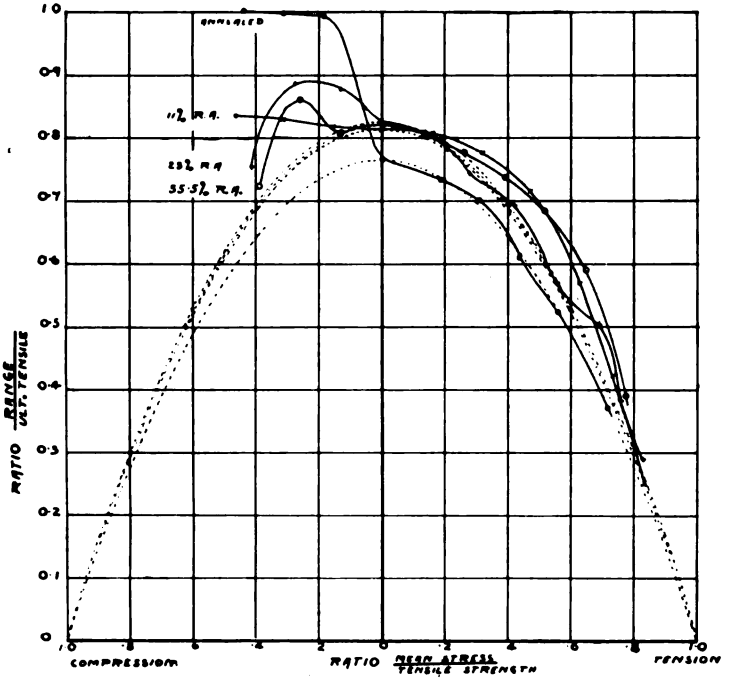

Fig. 23.

the mean stress to $-12{\cdot}42$ tons/in^2 at the end of the test, and the final range to 29·26, or 0·908 of the original tensile strength.

As a second approximation to the actual conditions, we may consider the effects of the cold work done in the Haigh machine. If it be assumed that the cold-setting operation increases tensile strength in the same ratio as did the cold-drawing operation, Fig. 19 would indicate a tensile strength of about 39·5 tons/in^2 for the aged material. The results obtained

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in tensile tests immediately after removal from the Haigh machine (Table VIII) indicate a strength which probably does not exceed 38 tons/in^2 before ageing. If this figure be taken, the mean stress at the end of the test is about ·327 of the final tensile strength, and the endurance range is about ·767 of the final estimated strength, values which differ very substantially from the values plotted on the conventional method.

It is to be expected that the curves will be unsymmetrical, and that the ranges in compression will be higher than those in tension. With mean tensile-stresses, the tendency is to reduce the sectional area and intensify the stress; the converse is true with respect to mean compressive-stresses. The results are interesting when considered in conjunction with an opinion expressed by Mr. H. J. Gough.*

"There is no doubt that more research could profitably be undertaken to investigate the relation between the safe range of stress and the mean stress of the cycle for a wide range of engineering steels and other metals. Particular attention should be paid to ranges of stress whose mean stress is compressive. Although the Gerber and modified Goodman relations assume the M/R curves are symmetrical about the axis corresponding to zero value of mean stress, we have seen that Haigh's tests on naval brass do not support this assumption. Also, observations of the resistance to repeated stresses of such components as connecting rods lead one to suspect that Haigh's results are not so exceptional as are commonly supposed, and that the fatigue ranges of certain steels—whose compression strength exceeds the tensile ultimate strength—will increase continuously (to an extent not yet known) as the mean stress of the cycle changes from positive through zero, to negative values."

The stress ranges in compression are certainly abnormally high, and it is interesting to note the capacity which the material has for healing slip lines while yet under stress, and

* Fatigue of Metals, p. 79.

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of building up a sufficient resistance to further deformation to enable it to carry the pulsating load, without fracture, for a very large number of cycles. At high stresses, tensile and compressive slip lines were clearly visible to the naked eye before full load had been reached. It is, therefore, clear that the development of slip lines does not indicate that fracture is immediately imminent. The progressive fracture theory of fatigue failure assumes that failure is due to initiation and progressive development of minute cracks. The present results show that the occurrence of slip bands, even to such an extent as to give the polished surface a frosted appearance, does not necessarily imply that fracture has commenced, or, alternately, that the rate of development of such fractures may be very slow. The longest run with slip bands showing in the present series was $18{\cdot}246 \times 10^6$ cycles; the specimen was unbroken. That cracks may develop very slowly was clearly seen in some of the tests under high mean compressive-stresses. Cracks which were clearly visible to the eye, and which could be felt with the finger nail, did not develop completely under several millions of stress cycles. In one case a crack was clearly visible when a specimen had been subjected to about 8×10^6 stress cycles; the test was stopped at $14{\cdot}68 \times 10^6$ cycles with the specimen still unbroken, although the crack had developed round about two-thirds of the circumference. Stress limits were $-1{\cdot}3$ and $-34{\cdot}7$ tons/in^2.

Engineering theories and calculations are generally based on the assumptions that the material is homogeneous and isotropic, and that Hooke's law holds for all stresses which may be applied to the material. In deducing formulæ, it is frequently convenient to assume that the material may be subdivided indefinitely into elements, and that the elastic properties of the elements will be unchanged.

These assumptions do not hold for any crystalline or fibrous material, since an element may be composed of one or more crystals or fibres. The formulæ obtained give useful results when applied to a large aggregate of particles, but it is not obvious that they will apply so accurately to purely local effects.

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Fatigue failures and failure due to impact are largely local phenomena, and they involve the initiation and development of cracks. Such tests may, therefore, give results which differ very considerably from those obtained by the slow tensile test. From this point of view, the constancy of the ratio between the endurance range and the ultimate strength is rather surprising; the constancy of the ratio is, as might be expected, not so apparent with non-ductile materials.

The process of failure may be divided into three stages:—

1. Elastic deformation.
2. Non-elastic deformation or slip.
3. Fracture.

Elastic deformation consists of slight distortion of the space lattice, and it is measured by the modulus. As the stress is increased, slip occurs along certain planes of weakness in the crystalline grains, atomic bonds are broken, and the disrupted particles slide over each other and form new atomic bonds with other particles. This action is known as slip. Slip occurs first in crystals whose planes of weakness are so unfavourably oriented with respect to the stressing force that they are subjected to tangential stresses. Slip necessarily involves a departure from the straight-line relationship of stress and strain, and the limit of proportionality is the stress at which the first slip occurs. This stress may be extremely low. Extensometers are not capable of detecting this first slip and the limit of proportionality as found by an extensometer depends, therefore, on the sensitiveness of the instrument. The stress so obtained does not define any fundamental property of the material, and it cannot be used in engineering calculations; also, it is not to be expected that any definite relationship between fatigue range and limit of proportionality will be in evidence.

The new atomic bonds formed after slip are frequently stronger than the initial bonds, and the strength of the material is increased. If the slip becomes excessive, healing of the slip lines does not occur, and submicroscopic cracks are probably formed; these cracks develop until failure occurs. The progres-

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sive development of such cracks can sometimes be clearly seen on the fractured surfaces of a test specimen after fatigue tests.

In cold-worked material, the easy glide of the particles has been very largely taken up, and the material is accordingly strengthened; such material, in general, shows no definite yield point, and it has much less general elongation.

The results obtained indicate that the fatigue stresses may themselves produce slip in the annealed material, and further slip in the cold-worked material, and yet, while undergoing fatigue stresses, and without any period of rest, the material may build up a resistance to failure which is truly astonishing. It is unnecessary that the material should be rested in a stress-free condition in order to permit of healing of the slip lines by the formation of new atomic bonds.

The safe range of stress which can be applied to any machine part depends on the mean stress, and the range of stress and the mean stress together define the upper and lower limits of stress which are permissible. It, therefore, seems to be logical to assert that factors of safety and working stresses should be based on range and mean stress, or on the upper- and lower-stress limits of any load cycle. The curves given illustrate some of the difficulties of the problem, and show that it is impossible with our present knowledge to estimate "safe" working stresses with any degree of certainty, and that our factors of safety must still include factors of ignorance.

The data given and the creep curves which follow indicate circumstances under which the determining factor would not be a strength but a strain characteristic. Even with pulsating stresses, conditions may arise under which failure would have to be defined in terms of creep or strain, rather than on a fatigue basis, which is generally taken to imply fracture.

The mode of failure with high mean compressive-stresses was interesting. If the range of stress exceeded the safe range by more than a small amount, the central section of the test specimen became barrel-shaped, causing a distinct groove to appear at the top and at the bottom where the barrel merged into the curved body of the specimen. The barrel gradually

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tilted, thus intensifying the depression at the top and the bottom of the barrel, but on opposite sides of the specimen. Fractures commenced at the points of deepest depression, and apparently about the same time. In all cases, the two fractures developed simultaneously until the machine cut out. When the range of stress was only slightly higher than the safe range, one crack only formed. This crack developed at the top or at the bottom of the barrel, but in no case did it develop at the section which had originally been smallest in area. Cracks developed in the same fashion when stresses were compressive at both upper and lower limits, but in such cases as already mentioned the rate of development was much more gradual. It should be noted that the bending mentioned was comparatively small; the ends remained approximately co-axial, and all unbroken specimens were removed from the machine, using the fingers only. The heads of the machine were carefully aligned before commencing the tests. Plug gauges, screwed to be a tight fit in the screwed sockets in the machine crosshead, were brought together, and the crossheads adjusted in alignment and inclination to permit of a ring gauge passing from one plug gauge to the other.

The earlier tests were made with specimens 4½ inches long, but at high mean-stresses creep was so large that the machine would frequently cut out owing to creep, and if the cut-outs were adjusted to give a greater clearance, the stress would go too far out of balance overnight. The shorter specimen shown in Fig. 11 was, therefore, adopted. It is probable that longer specimens would give lower results than those recorded in Table VII, but if results are obtained for short specimens, an approximate estimate of the ultimate capacity of the material for resisting fluctuating stresses is obtained, and the effect of length can be allowed for.

Strain Energy Relation.

The following discussion of the strain energy relation is due to Mr. T. M. Jasper*:—

* Illinois Bulletin, No. 142, and Philosophical Magazine, Oct., 1923.

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In discussing Prof. Haigh's theory that the criterion for limiting strength of a material is a definite quantity of energy per unit volume, and that this quantity of energy is the strength constant of the material, Mr. Jasper suggested that, under such conditions, the amount of strain energy per unit volume per cycle of stress developed at the endurance limit for reversed stress, would be found to be the same as that developed at the endurance limit for all mean stresses. Thus:—

Let S_1 be the maximum stress, and
S_2 the minimum stress $= rS_1$,

where r is the ratio $\frac{\text{minimum stress}}{\text{maximum stress}}$.

It is further assumed that the endurance range is an elastic range, and that an elastic range necessarily gives a straight-line stress-strain diagram both for tensile and for compressive stresses. The energy per unit volume per stress cycle is then represented by an area under the stress-strain line.

Then, for all stresses,

$E_1 =$ the energy per unit volume per cycle

$= \frac{S_1^2}{2E} \pm \frac{S_2^2}{2E}$, the + sign being used when S_1 and S_2 are of opposite sign;

or $E_1 = \frac{S_1^2}{2E}(1 \pm r^2)$, if $r = -1$ as when the stresses are equal and opposite (complete reversal).

$E_r = \frac{Sr^2}{2E}(1+1) = \frac{Sr^2}{E}$, where $\pm S_r$ is the reversal range.

Then for equality under all conditions of loading, we must have

$$\frac{S_1^2}{2E}(1 \pm r^2) = \text{constant} = \frac{S_r^2}{E},$$

or

$$\frac{S_1}{S_r} = \frac{2}{1 \pm r^2}$$

It will be noticed that with mean compressive-stresses S_1 decreases, Fig. 24 (a) and (b), and that the ratio

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$r = \frac{\text{minimum stress}}{\text{maximum stress}}$ increases numerically, becoming infinite when $S_1 = 0$ and positive for negative values of S_1. It is obvious that the method fails unless values are calculated for numerical ratios only. Hence for mean compressive-stresses the notation is as shown in Fig. 24 (c) and the negative value of S_r taken, thus giving a positive value to the ratio $\frac{S_1}{S_r}$. The values so obtained are tabulated in Table VII and plotted in Fig. 25.

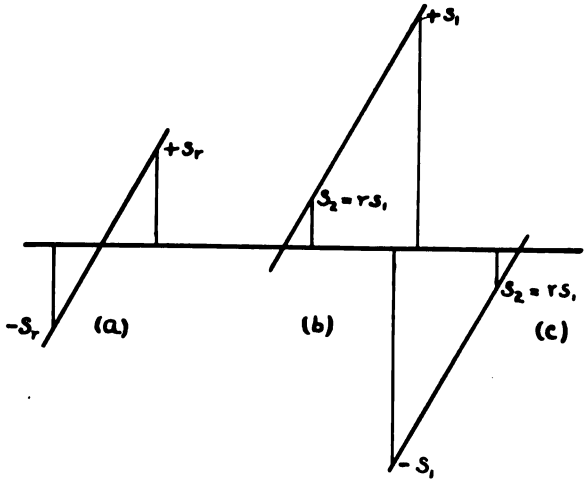

Fig. 24.

It will be noticed that the mean straight line which most nearly fits the points plotted does not pass through the point representing $r = -1$; that is, the case for reversed stresses. The line

$$\frac{S_1}{S_r} = 1{\cdot}77 + r$$

lies very evenly among the points representing tests with mean tensile-stresses on the annealed material. It is difficult to see why a straight line should fit such a series of tests when the maximum stresses used in the cycle ranged up to nearly

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29 tons/in², with a material of slightly greater than 32 tons/in² tensile strength. It is obvious that the assumption made that the endurance range is an elastic range, and is represented by a straight-line diagram, is not even approximately true under such conditions of test. The same line fits the observations on cold-worked materials moderately well, although there are greater departures from proportionality in this case.

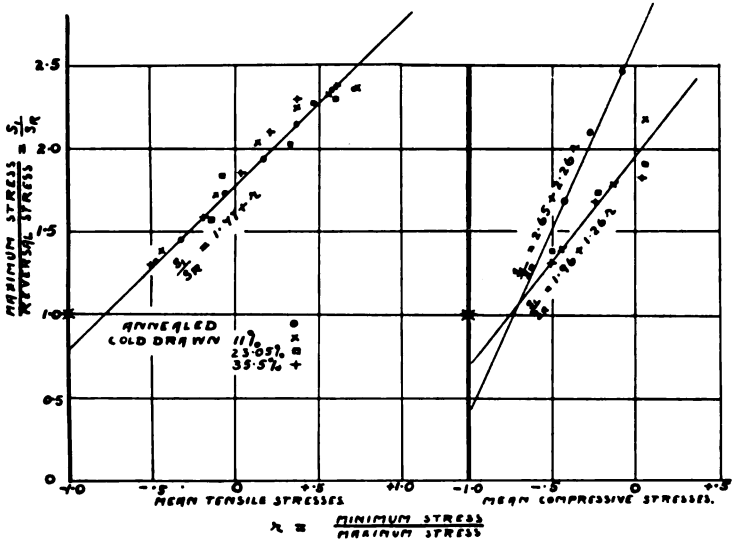

Fig. 25.

With mean compressive stresses, Fig. 25, the points representing experiments on annealed and cold-worked metals fall into two distinct groups.

The annealed material follows, approximately, the relationship

$$\frac{S_1}{S_r} = 2{\cdot}65 + 2{\cdot}26r,$$

and the cold-drawn, the relationship

$$\frac{S_1}{S_r} = 1{\cdot}96 + 1{\cdot}26r.$$

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Mr. Jasper found that the approximate relationship which existed in his tests was

$$\frac{S_1}{S_r} = \frac{r+3}{2}.$$

The relationship is probably considerably influenced by the type of machine used and by the nature of the stress wave imposed on the material.

EFFECT OF FLUCTUATING STRESSES ON TENSILE STRENGTH.

In a paper already mentioned* (R. and M. 1012), Messrs. Gough and Tapsell quote figures (Table XVII, page 19) showing that by understressing it was possible to raise the fatigue range by 28·2 per cent. using a 0·13 per cent. carbon steel. During the earlier experiments in the present series, when a specimen was unbroken at the end of a test, the stress was sometimes raised to determine, approximately, the endurance range that was to be expected. It was found that such tests were of little value as rangefinders, and that the ranges indicated were invariably too high. The investigation as to the extent by which the endurance range could be raised by understressing was not proceeded with on account of the time required, but it was found that, with very high mean tensile-stresses, it was possible to train a specimen to such an extent that an endurance of 12×10^6 cycles could be obtained with maximum stresses which exceeded the normal statical ultimate strength. The test at 36 tons/in^2 initial stress, range 12·6 tons/in^2, giving a maximum stress of 42·3 tons/in^2 with an ultimate strength of 43·61 tons/in^2 (Table VII), shows how little additional training is necessary.

It was, therefore, decided that specimens, unbroken in fatigue tests, should be tested in a statical testing machine in order to find out whether, and to what extent, a fatigue test affected the statical properties as determined by a normal test. Owing to the shape of the specimens, it was only possible to investigate the ultimate strength in tension and the percentage reduction of area.

* Ibid., p. 536.

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The results, given in Table VIII, are incomplete as regards the earlier tests made at low mean tensile-stresses on specimens in the annealed and cold-drawn conditions (23 per cent. reduction of area). The results available are too small in number to permit of any very definite statements being made, but the few general observations which are permissible show that, so far as the annealed material is concerned, there is probably a slight increase in tensile strength when the range of applied stress has a mean tensile value. The increased reduction of area is rather surprising, and requires verification. With mean compressive-stresses the gain in tensile strength is fairly definite, and is not fully accounted for by the gain in area of the specimen during the fatigue test. The increase is not so definite at the highest mean-stress. The decrease in ductility is quite definite.

With regard to the cold-worked material, for all degrees of cold drawing there is a slightly increased tensile strength, accompanied by reduced ductility, when the mean stresses in the stress cycles are tensile. When mean compressive-stresses have been applied, a mean stress of -6 tons/in^2 improves the tenacity of the material which has been cold drawn 11 and 23 per cent.; with mean stresses of -12 tons/in^2, the increased tenacity is practically accounted for by the increased area of the test specimen after the endurance test. With the highest mean-stress of 18 tons/in^2, the tensile strength is definitely reduced, either absolutely or in comparison with the increased area of the test specimen. The most severely cold-drawn material (35·5 per cent. reduction of area) shows a definite increase in tensile strength with all mean stresses used.

Creep under Pulsating Loads.

In recent years much work has been done in investigating failure due to creep under steady loads. This work has been done mainly at high temperature, since creep phenomena are relatively unimportant at normal temperatures. The significance of creep under pulsating stresses has perhaps not been

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so fully appreciated. When a reversed stress is applied to a material and failure takes place after a large number of stress cycles, the failure is said to be due to fatigue, and many theories have been advanced to explain such failures. As the mean stress is raised, the permissible range of stress diminishes, but the maximum stress applied increases, although at an ever diminishing rate. Under such conditions it is to be expected that the effects of fatigue, due to range of stress, will diminish as the range diminishes, and effects due to creep will become increasingly important as the maximum stress increases, and that ultimately the effects of creep will predominate over those due to fatigue, and failure will be mainly due to creep. The combined effects of creep and fatigue are very complex, but in many cases the effects must be considered in conjunction with each other if causes of failure are to be fully explained.

Prof. Lea* has shown that, under reversed stresses as the temperature is raised, the safe range of stress tends to follow the ultimate-strength curve rather than the creep-strength curve; that is, the decrease in endurance range with rise of temperature is not nearly so marked as the decrease in the creep strength. It by no means follows that at high mean-stresses and high temperatures the fatigue range will not diminish more rapidly in accordance with the rapidly diminishing creep strength. In the present investigation, the effects of cold drawing are under consideration, and as this material is suitable for use at, or near, normal temperature, temperature effects have not been considered.

The results are somewhat incomplete, because the significance of the creep phenomena was not fully appreciated until several tests at high mean-stresses had been carried out. An approximate estimate of the amount of creep was obtained by fitting a graduated dial and pointer to the spindle on the Haigh machine, which is used for centralising the air gaps. The method may not be capable of a high degree of accuracy, but it is quite satisfactory for measuring the relatively large changes which occur when creep phenomena become important.

* Proc. Inst. Mechanical Engineers, vol. ii, 1924.

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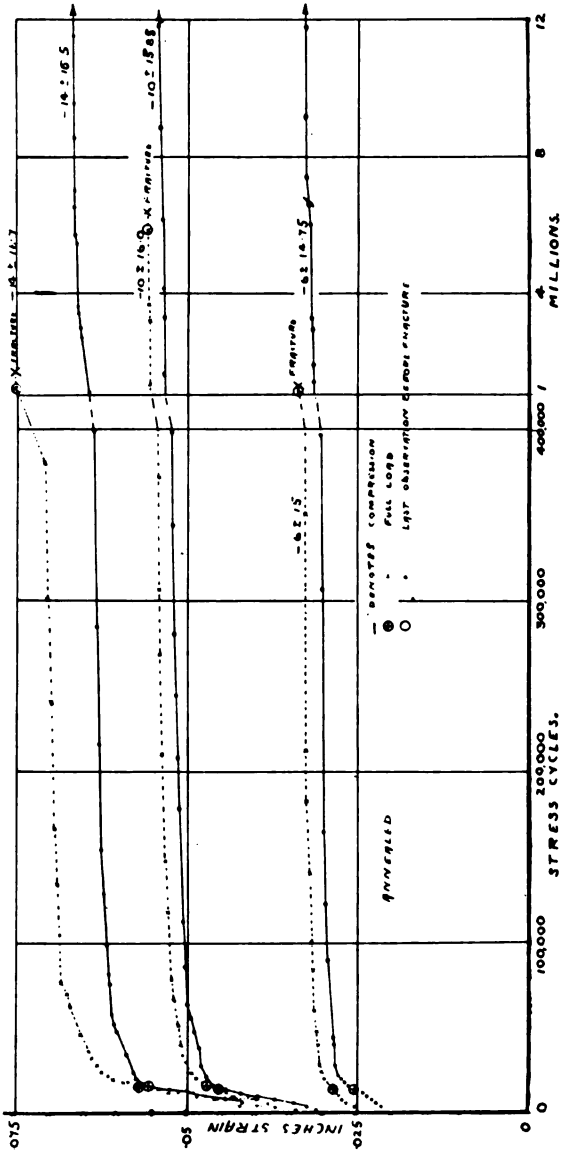

Fig. 26.

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The velocity ratio of the gear was 106·66; one degree revolution of the spindle, therefore, corresponds to a change in position of the screwed socket in the upper crosshead of 0·00002578 inch. The worm and screw gear cannot be relied on to this degree of accuracy, but the gear is sufficiently accurate for qualitative results. The shape of the specimens does not lend itself to accurate quantitative results, but as the specimens were machined in a profiling lathe, and were of approximately standard dimensions, the results may be regarded as reasonably comparable. In the earlier tests,* a Haigh specimen, 4½ inches long, was used. This proved to be satisfactory for tensile tests, but was not nearly so satisfactory for compression tests where the combined effects of buckling and creep were large. In such tests the machine could not be left unattended overnight. It was, therefore, necessary to use the shorter and stiffer specimen shown in Fig. 11 in all subsequent tests. The diameter could not be increased owing to the limited capacity of the machine. Check tests made with reversed stresses indicated that the specimen had not been altered sufficiently to affect the endurance ranges with mean tensile-stresses.

In all series of tests it was found that as the mean stress was raised, it became increasingly difficult to obtain S/N curves. Ultimately the difference in range between a specimen which would fracture at once and one which would run 12×10^6 cycles was a matter of very fine adjustment, and such tests could only be run with battery excitation during the summer months, when there was no other load on the battery.

Table VIII gives some typical results. The difficulty of obtaining an S/N curve with high mean tensile-stresses is clearly shown by the figures. It will be seen that the reduction of the range of stress by a fraction of a ton increased the endurance from a few thousand cycles to at least 12×10^6 cycles; that is, the whole S/N curve was contained within a fraction of a ton/in^2 range. This indicates the presence of a fairly definite creep limit under such conditions of stressing. If the creep limit was exceeded by a small amount, creep

* Trans. of the Institution, 1926, vol. lxix, p. 383.

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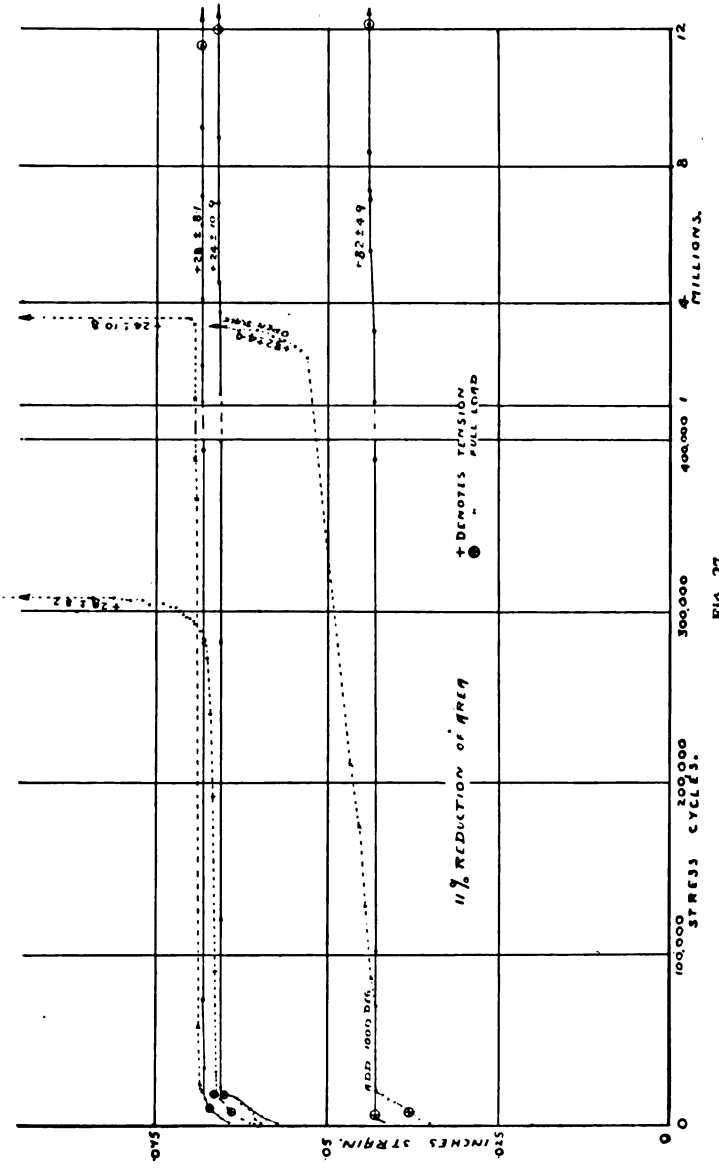

Fig. 27.

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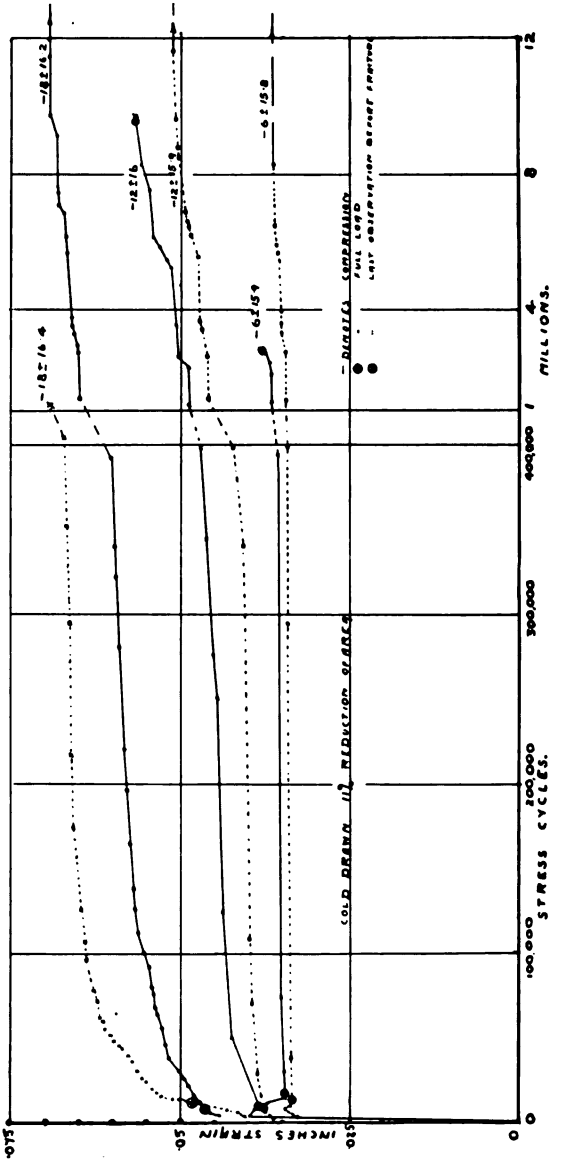

Fig. 28.

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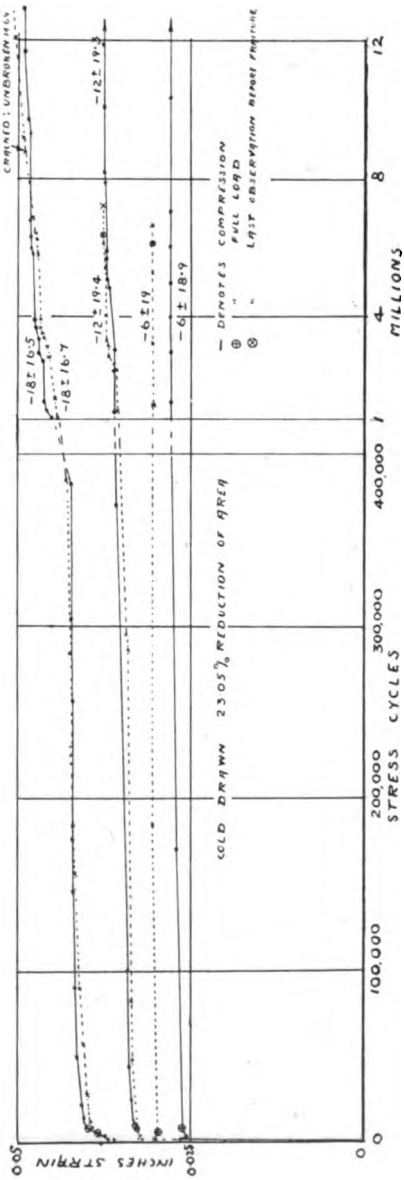

Fig. 29.

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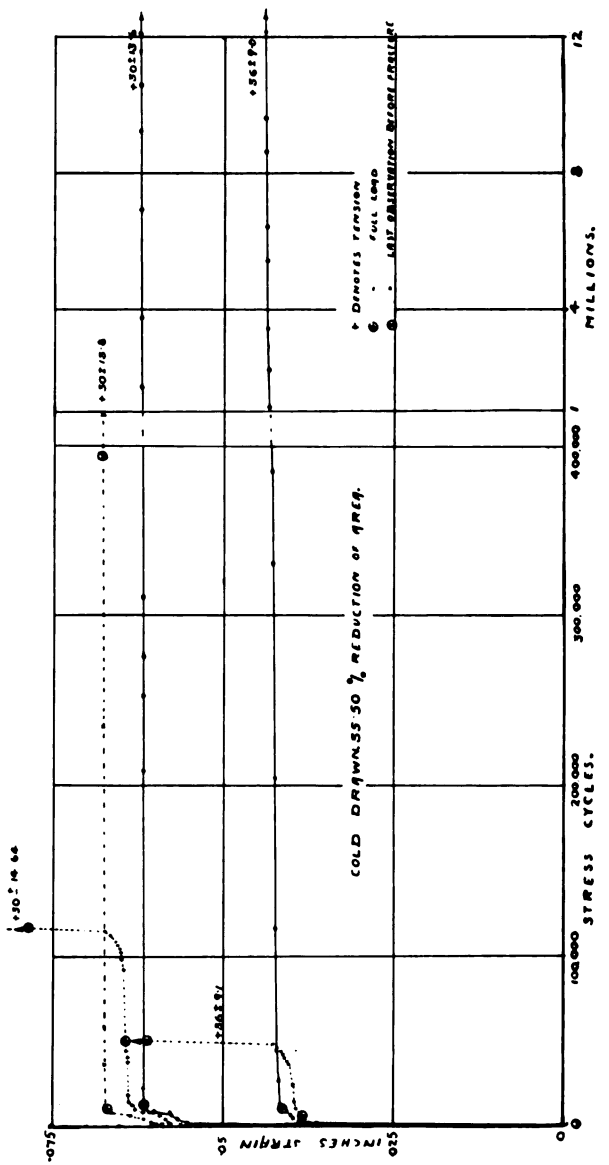

Fig. 30.

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became continuous, and the increasing stress intensity rapidly caused failure to occur. To permit of such loads being applied, it was necessary to increase the load by small increments. This may provide a certain limited amount of understressing. The cycles up to full load are, therefore, included in Table VIII, to indicate to what extent this understressing had occurred. The loading period was kept as short as possible in order that the training effect of understressing should be a minimum. The periods may have been sufficient to permit of at least partial removal of the transient hysteresis, which is indicated by a fall in temperature of the specimen, but this point was not investigated.

The strains recorded are not to be regarded as strictly comparable, since there was no method of obtaining an initial zero reading with accuracy. The heads of the machine were adjusted to give the position in which the specimen could be screwed into the grips most freely, and the zero reading was taken in this position. Hence any slackness in the screw threads, etc., is recorded as strain during the loading period; readings obtained during this period are, therefore, very variable.

In a few cases only was a break actually observed at the end of a run of considerable duration. Some of these tests are plotted in Figs. 26-31, and show that there was a sudden drawing out of the specimen immediately before failure. The figures in the table, generally of necessity, omit the strain which occurs immediately before failure, and the recorded strain may be that which was observed, perhaps 1,000,000 cycles, or thereby, before fracture actually occurred. The graphs show only tests at high mean-stresses; the figures in Table VIII indicate that creep was relatively unimportant at low mean-stresses.

It is clear from the diagrams that creep is an important factor in causing failure under high mean-stresses, that creep has not ceased at 12×10^6 cycles, and that, therefore, failure is still probable. The curves show that very long tests must be carried out if the vexed question as to whether there is a

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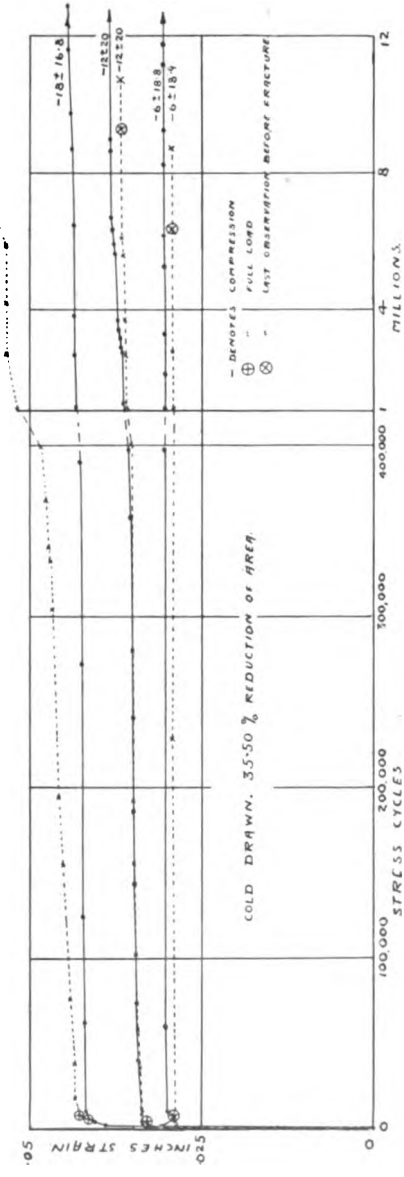

Fig. 31.

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definite endurance range for indefinite life, is under investigation.

The tests show that creep appears to be the predominating factor if the mean stress exceeds about half the ultimate strength, but the number of tests is insufficient to locate the ratio with any degree of accuracy. It probably varies greatly with the material and with the stress cycle impressed on the material. If the ratio remains approximately constant at increased temperatures, creep may become very important at relatively low mean-stresses if the temperature be sufficiently high.

Effects of Grain Direction.

In most engineering calculations, it is assumed that the materials used are homogeneous and isotropic, and that their properties are identical in all directions. This is not strictly true of any material; the grain size and the alignment of the grains or crystals are greatly influenced by the processes through which the material has passed during manufacture. It would, therefore, appear to be probable that cold-drawn material, in which the crystals have been elongated by cold work, would have physical properties which vary with the angle of inclination of the axis of the test specimen to the axis of drawing. A series of experiments were, therefore, carried out to investigate the effects of grain direction on cold-drawn mild steel.

The material used had the following composition:—

	Per cent.
Carbon - - -	0·10
Silicon - - - -	0·02
Manganese - - - -	0·39
Sulphur - - - -	0·028
Phosphorous - -	0·021

The analysis shows that the steel is of very high quality, and it is typical of many high-grade steels used in the cold-drawn condition, as profile steel, for special purposes. It was prepared by Messrs. Bruntons, Musselburgh, and it had undergone normal commercial treatment.

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Bars, $4\frac{1}{16}$ inch by $\frac{9}{16}$ inch thick were drawn to 4 inches by $\frac{1}{2}$ inch; the reduction of area was, therefore, 12·48 per cent. Part of the material was annealed by Messrs. Bruntons, and part was supplied in the cold-drawn condition.

Test pieces were cut from the axis of the bars, and also at angles to the axis, which increased by 15-degree steps from 0 to 90 degrees. This scheme gave specimens which could be compared in pairs at right angles to each other, and by determining surface hardness the hardness on three mutually perpendicular planes could be investigated.

The tensile test pieces were approximately $\frac{3}{8}$ inch in diameter, and they were screwed at the ends. A Ewing extensometer was used giving a reading of $\frac{1}{12.500}$ inch on two inches for each division on the scale, and by estimation a reading of $\frac{1}{125.000}$ inch could be obtained with fair accuracy. Wöhler specimens were turned in a profiling lathe, and were of the same form as the small specimens used in the earlier research. Izod tests were at first made on circular specimens ·45 inch in diameter notched at random, but after the tensile specimens had been broken and an oval formation at fracture noted, it was decided to use square specimens and to investigate whether there was any decided difference in the test results, if specimens were notched parallel to or perpendicular to the surface of the plate. Check tests were necessary also on account of the unexpected results of the Izod tests in the circular specimen. The results of the tests are given in Tables IX and X, and are shown graphically in Figs. 32 and 33.

The tables and curves confirm the opinion that grain direction has no influence on modulus, limit of proportionality, proof strength, or ultimate strength of the annealed material, but that it greatly influences percentage elongation and reduction of area.* The curves are similar in form to those obtained by Mr. Brearly in tests on a nickel steel, except as regards the Izod test results.

It will be seen from the graphs that of the properties which can be investigated by the tensile test, only elongation and

* Aitchison. "Engineering Steels," p. 30.

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Position.	Ratio. W.R. / Ult.	Izod (Mean). Ft. Lbs.	H5/750/15 Tested on Thickness.	Brinell Factor based on		
				Tests on Thickness.		Tests on Face of Plate.
				// to Axis of Specn.	⊥ Axis of Specn.	
Along Axis	·895	20·36	105·6	·207	·210	·231
15° to Axis	·861	18·85	106·1	·208	·210	·232
30°	·873	14·25	107·0	·206	·205	·232
45°	·846	14·62	[illegible]			

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Inclination to Axis of Bar.	PERPENDICULAR TO FACE.			Mean.	Mean (Square).	Mean (Overall).
0°	20	19·7	16·5	16·57	19·03	20·36
15°	21			15·93	18·85	18·85
30°	19			14·80	15·53	14·25
45°	15			16·37	15·68	14·62
60°	17			15·33	18·66	17·14
75°	19			22·77	26·92	24·39
90°	43			31·17	31·17	35·30
0° (Axis)	5			7·10	8·44	7·88
0° (Edge)	6			7·23	7·57	7·03
15°	9			7·50	7·63	7·62
30°	2	6·0	6·0	6·70	6·95	6·70
45°	4			7·10	6·66	6·29
60°	6			7·23	7·82	7·22
75°	6			6·33	6·90	6·63
90°	7			4·73	5·32	5·37

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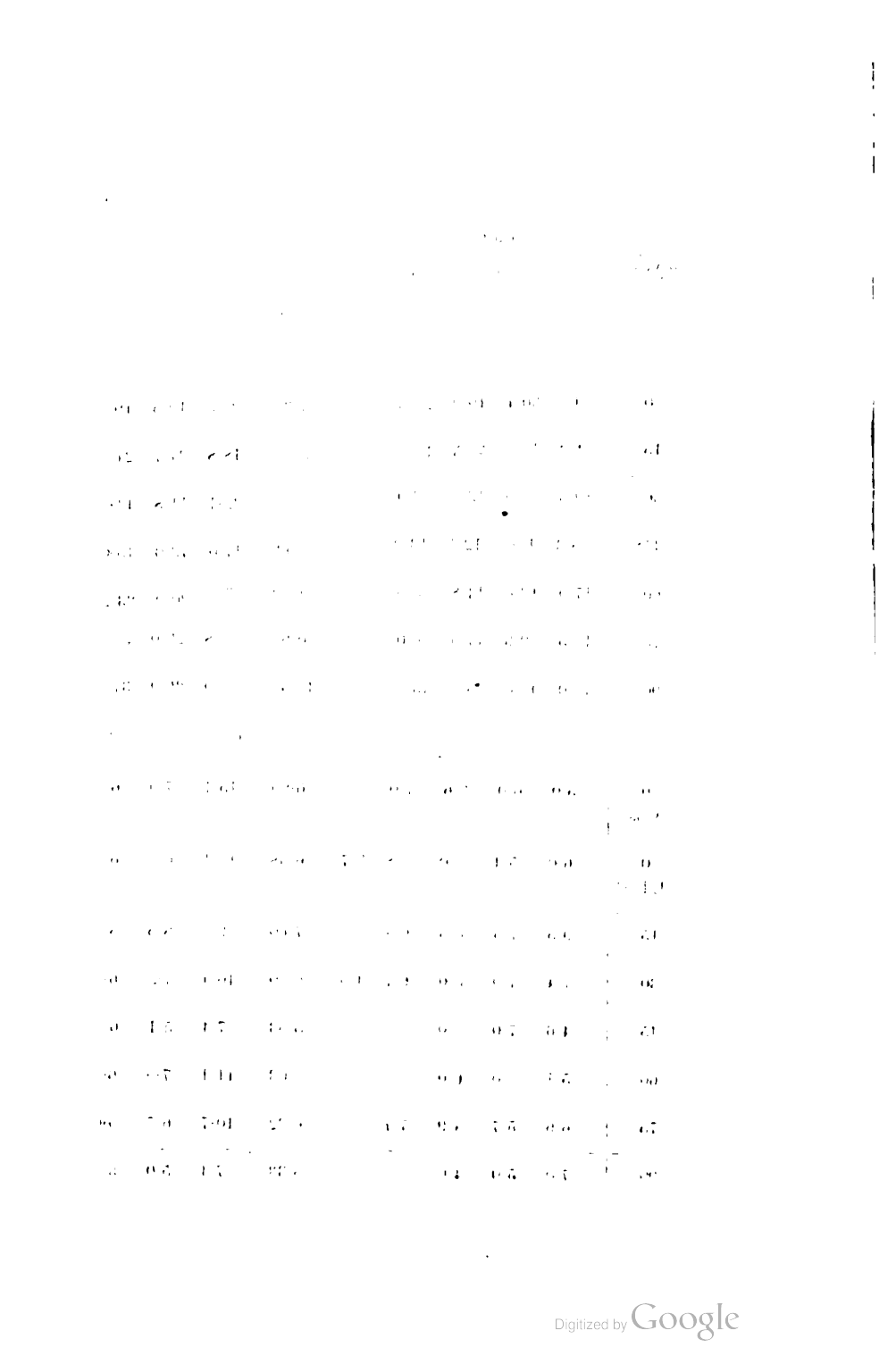

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reduction of area are affected by the grain direction. This statement applies equally to the cold-drawn material, in which, as might be expected, the effect of grain direction would be more pronounced. In the present case the percentage reduc-

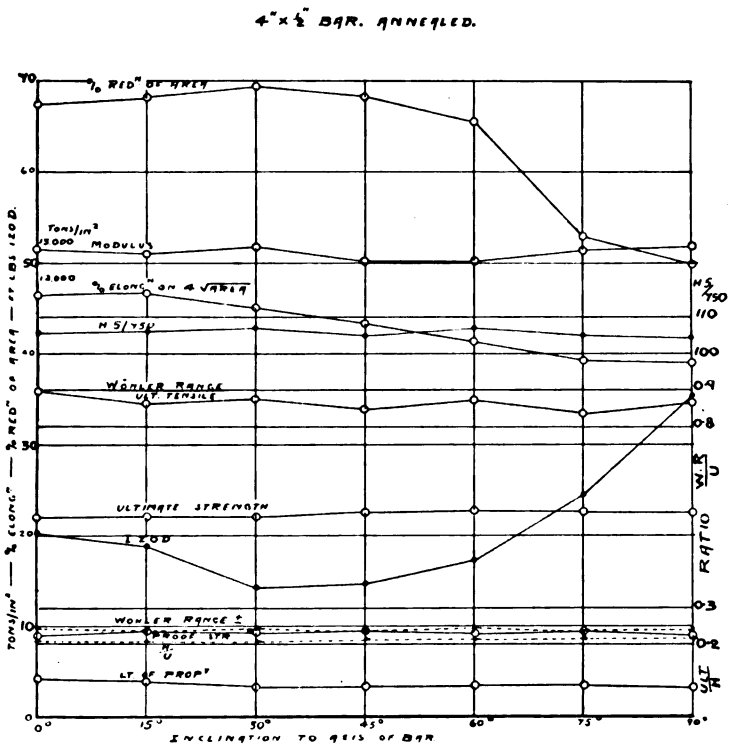

Fig. 32.

tion of area is small, and it is by no means certain that similar results would be obtained with heavy reductions of area. The reduction of area is typical of that used for complex sections of drawn material; that is, for those sections in which the applied forces are most likely to be inclined to the axis of drawing.

One curious feature was noted in the tensile tests on the annealed bar. In the case of specimens cut from the axis of

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the bar, the form of the neck after fracture was very decidedly oval. Check tests made confirmed the fact that the major axis of the oval was parallel to the 4-inch edge of the plate. The ratios of major to minor axis are given in Table IX. It will be noticed that the ratio diminishes from a maximum for

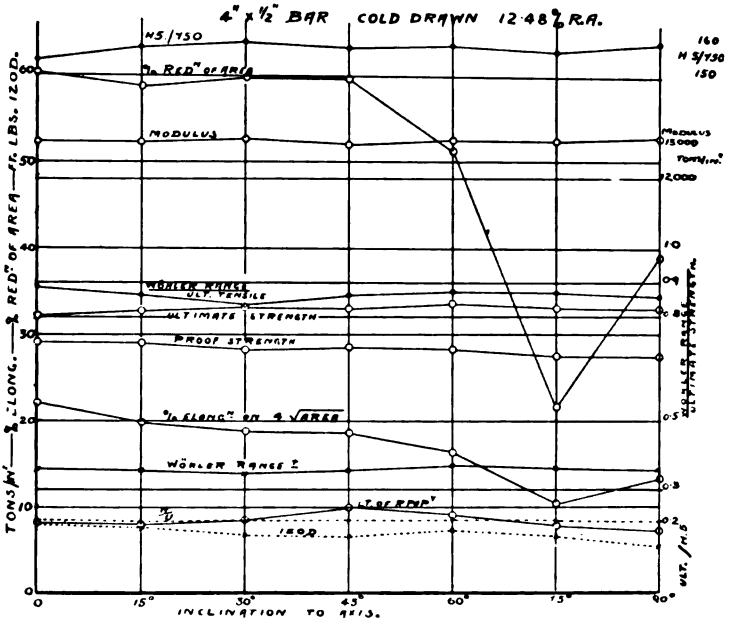

Fig. 33.

axial specimens to a minimum for specimens cut at 45 degrees, and was thereafter relatively unaffected by angle of inclination. The effect is very much less marked in the case of the cold-drawn material, and in this case the effect is nearly constant; the variations between different specimens in the same group were as great as the difference between the mean figures quoted for the groups. The oval formation was also noticeable along the body of the specimen, at points far removed from the section at which fracture had taken place.

Tensile test specimens at 75 and 90 degrees showed sliding

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fractures. In the case of the annealed material, the angle of fracture of the 75 degrees test specimens varied from 59 to 70 degrees to the axis of the test specimen; in the case of the cold-drawn specimens, the angle was 63 degrees in one case and 75 degrees in three cases; that is, directly perpendicular to the axis of drawing. Specimens cut at 90 degrees to the axis of the plate failed at angles which varied from 86 to 90 degrees to the axis of the test specimen.

Brinell tests are interesting when considered in conjunction with the oval formation at the neck. It will be seen that the surface of the plate was decidedly softer than the cross-section. When necking was commenced, the greater part of the cold flow took place in the softer material, and this probably explains the excessively oval formation when specimens are nearly parallel to the axis of the plate. The ratios $\frac{\text{ultimate strength}}{\text{Brinell hardness}}$ are slightly higher than normal if calculated for the hardness number found for the surface of the plate, but are decidedly lower when based on the figures obtained in tests on the thickness; the value is almost the same whether the ratio be based on a test on the axis of the specimen or parallel to the axis, so long as it is obtained on the thickness of the plate. The results are similar in the case of the cold-drawn material. The lip of the Brinell impression was depressed in all the annealed tests, but was raised in the tests on the cold-drawn material.

The Wöhler tests show that the range for reversed stresses is practically unaffected by grain direction, either in the annealed or in the cold-drawn material. The average value of the ratio $\frac{\text{range of stress}}{\text{ultimate strength}}$ is the same for annealed and for cold-worked material. The ratios are somewhat low. The surface of the tensile test specimens showed an abnormal amount of crinkling, thus indicating that the material was large grained. The low ratio is in general agreement with the opinions expressed by Messrs. Moore and Jasper,* namely, that

* Illinois Bulletin, No. 142, p. 11.

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"the larger and more angular the grains, the greater would seem to be the tendency to localised bearing stress of grain on grain, and the lower the general statistical stress which will cause failure."

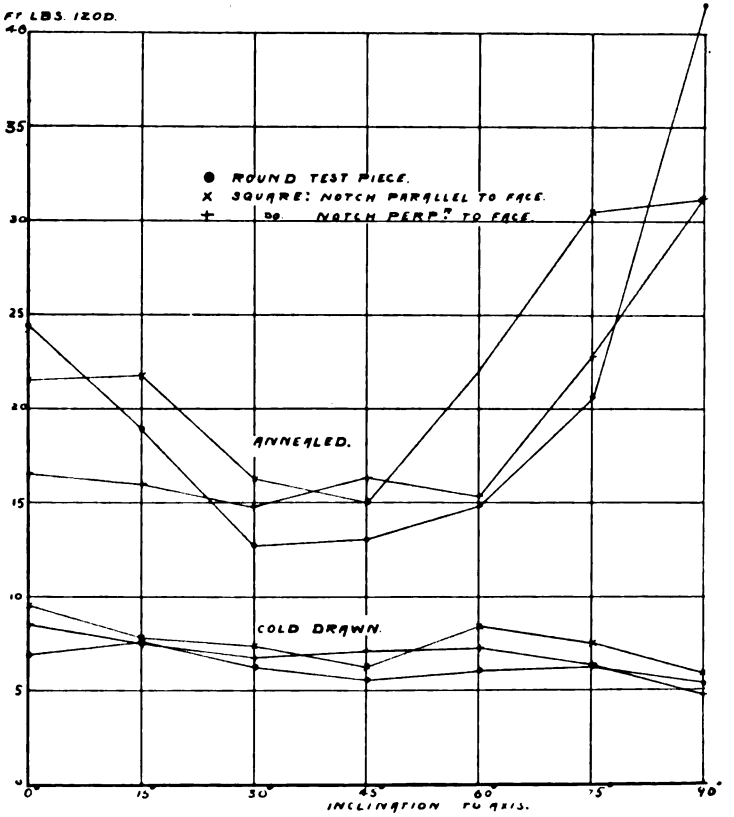

Fig. 34.

The annealed steel shows the very curious result that the Izod figure reaches a minimum value when the angle of inclination is between 30 and 45 degrees to the axis of the bar, and that it reaches a maximum value when the specimen is cut transversely. This is true with round and with square

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specimens. After the round specimens had been tested, it was decided that square specimens would be more suitable for the check tests, and that notches should be cut parallel to and perpendicular to the surface of the plate. If a steel is laminated, the Izod value may be abnormally high if notches are cut parallel to the laminations, since the development of the crack may be interrupted by the lamination; if, on the other hand, the notch be cut perpendicularly to the lamination, free development of the crack may proceed on either side of the lamination, and the Izod figure is, therefore, lower than in the former case.

Details of the Izod figures are given in Table X, and the results are plotted in Fig. 34. The results show that notches cut parallel to the face of the plate give higher values than those cut perpendicularly to the surface; that is, across the thickness of the plate. This difference may be due to some laminal effect, or it may be due to differences in hardness in the two planes. In all cases the line of fracture was perpendicular to the length of the specimen, and laminations were visible in specimens cut at angles of 60 degrees and upwards. All Izod curves, however, show increased values as the angle is increased from 45 to 90 degrees, and this condition may be accepted as confirmed. The cold-drawn material showed relatively little grain angle effect, although the general trend is towards a lower value as the angle of inclination is increased. The results differ entirely from those obtained by Mr. Brearly in his tests on heat-treated nickel steel.*

Profile Mild Steel.

The uniformity (or otherwise) of the properties at different points on the cross-section of a bar of cold-drawn steel of irregular outline will depend largely on the cross-section and on the distribution of cold work over the section. Conditions may, therefore, be very variable, and no general conclusion can be drawn from a few experiments. Normally, a skilled wire-

* Aitchison. Engineering Steels, p. 31.

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drawer will design his dies so that the proportion may be as uniform as possible over the cross-section.

As a matter of interest, it was decided to make a few tests on a bar of steel of somewhat irregular section, and a bar of material of the outline shown in Fig. 35 was selected. The bar was manufactured by Messrs. Bruntons, Musselburgh, and was prepared in the normal way; it was chosen because it had a more irregular outline than any other bar which was then under process of manufacture. The bar was drawn in a split die, and it was removed from the die when half the length had been drawn; one-half of the bar was, therefore, in an

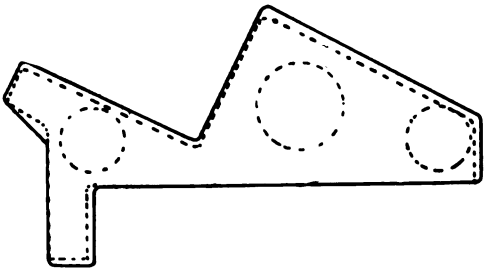

Fig. 35.

annealed condition, and the other half in the cold-drawn condition.

Fig. 35 was prepared from rubbings of the cross-sections. The percentage reduction of area was about 11·2 per cent.

Analysis showed the following composition:—

	Per cent.
Carbon - - -	0·10
Silicon - - - -	0·10
Manganese - - -	0·50
Sulphur - - -	0·034
Phosphorous - -	0·039

The test results are given in Table XI.

Little comment is necessary, because the results are peculiar to this particular cross-section. The tensile tests on the drawn material show, as might be expected, slightly higher

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Table XI.

	Position	Modulus. Tons/In.²	Limit of Proportionality. Tons/In.²	1st Creep. Tons/In.²	Proof Stress. Tons/In.²	Ultimate Strength. Tons/In.²	Elongation on $4\sqrt{\text{Area}}$. Per cent.	Reduction of Area. Per cent.	Wöhler Range. Tons/In.²	Ratio. $\frac{\text{W.R.}}{\text{U.}}$	Izod.	H.5/750.	Ratio. $\frac{\text{U}}{\text{H}}$	Remarks.
	ANNEALED MATERIAL.													
	1	12,760	7·26	8·23	13·07	23·04	43·22	69·79	±10·7	0·929		106·5	0·216	General elongation about 20 per cent.
	2	12,410	6·07	11·76	13·20	22·71	46·59	70·74	±10·5	0·925	15·5	106·4	0·213	
	3	12,540	4·64	7·22	13·10	22·08	44·06	68·20	±10·4	0·942		110·7	0·199	
	COLD-DRAWN MATERIAL.													
	1	12,940	7·85	22·14	28·78	32·02	25·07	63·57	±13·0	0·812		147·3	0·217	General elongation about 5 per cent.
	2	12,650	8·87	22·19	25·68	23·09	27·12	68·69	±12·6	0·896	3·1	143·5	0·196	
	3	12,450	7·12	21·27	27·04	29·92	26·69	64·27	±12·4	0·829		149·5	0·200	

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results for the thinner portions of the cross-section than for the thicker portions, where the mass is much greater and the effects of the small amount of cold work less felt. The endurance ranges fall into the same order of magnitude, but the ratios vary somewhat, the section with the lowest tensile-strength showing a ratio which most closely approximates that for the annealed material, and the section of greatest tenacity (greatest amount of cold work) shows the lowest value.

The material was again very large-grained, which probably accounts for the very low values obtained in the Izod test and for the high values obtained for the ductility in the tensile tests. The tensile test sections again showed a tendency to conform to the original outline of the bar. Test pieces from section 2—annealed and cold drawn—show a decidedly triangular formation, but the effect was not so clearly noticeable on the smaller sections 1 and 3. The fractured sections in these cases appeared to be more egg-shaped.

Summary and Conclusions.

Engineering materials are subject to so many variable factors that it is seldom possible to be able to regard conclusions, deduced from one research, as definitely proved. A single research can only indicate probabilities; many researches are generally required to give a definite proof. In summarising results, therefore, it is right to indicate that certain results appear to be true within the limited scope of the experiments.

In the present case, the conclusions indicated are:—

1. That, when a material has been cold worked to such an extent that plastic flow has taken place, the internal stresses are due to the elastic recovery of the material, and are, therefore, not proportional to the amount of cold work done. The stresses increase as the elastic recovery increases, and lesser degrees of cold working, therefore, appear to give higher internal-stresses. A research of greatly extended scope is being undertaken to investigate the question more fully.

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2. That, with a highly ductile material, the relief of internal stress consequent on machining, though it may be very considerable, has no appreciable effect on the properties revealed by statical tensile or by Wöhler tests, and that the results of tests obtained on any diameter may be accepted as reasonably characteristic of the material. The above statement applies to materials which have been moderately cold-worked, and is not necessarily true if the cold working has been very great.

This statement appears to be open to much criticism. It seems to be obvious that a material will fail when the sum of internal and external stresses reaches a limit for the material. It should, therefore, be noted that the limit of proportionality for the material was so low that the extensometer methods failed to detect any decided differences within the so-called elastic range. When plastic conditions supervene, and Table III shows that this occurs at low applied loads—probably lower than those marked as 1st creep—the internal stresses are necessarily relieved, and phenomena which occur at higher stresses are relatively unaffected.

With regard to fluctuating stresses, such stresses assist the material to recover the stress-free condition, so far as internal stresses are concerned. The most stable condition for a material or a structure is the condition which permits of the least absorption of work under any specified conditions of loading. That some internal readjustment takes place is clearly indicated by the heat bursts detected by thermodynamic tests. In a few of the earlier reversed stress experiments carried out in the Haigh machine, multiple thermo-couples in series, of a type used by Prof. Haigh, to whom I am indebted, indicated that at first there was a rise of temperature, which was rapidly followed by a fall in temperature; this signified that the condition of the material for, approximately, least absorption of energy had been reached. In some experiments, the temperature changes could be detected by the fingers. Hence, in a long test, it would appear to be probable that the internal stresses would become so sufficiently relieved

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that the residual stress had no appreciable effect on that result.

The qualification "highly ductile" is probably necessary, and it by no means follows that similar results would be obtained with brittle materials. A similar research carried out with a brittle material might give interesting results. Ductility permits of internal rearrangements which relieve internal stresses, or stress concentrations due to sharp corners, scratches, etc., provided the duration of the test is sufficiently long to allow the necessary changes to occur. The necessary time is available in slow tensile tests or in endurance tests, but it is probably not available in shock tests. The Izod test does not lend itself to testing on different sizes, and the effects of machining on impact properties could not be determined. Tensile impact tests, if such tests could be carried out on unnotched bars, would be more directly comparable, and would probably give some useful results.

3. That, as the mean stress in a fluctuating stress cycle is raised, creep phenomena become more important than the usual fatigue effects, and that, ultimately, creep effects predominate and determine the endurance range.

In the present experiments, when the mean tensile-stresses exceeded rather more than one-half of the ultimate strength, fairly definite creep limits were indicated, and it became excessively difficult to get a test specimen which would run for two or three million cycles. Specimens either failed after very few cycles, or were unbroken after a run of 12×10^6 cycles. The S/N curves were, therefore, very flat.

The values with cold-drawn material were in general somewhat higher than those predicted by Gerber's parabolic law, but agreed very closely with the parabola for the annealed material. The Gerber law appears to give reasonably safe values under all conditions. The reason why the cold-drawn material gave higher values, relatively, than the annealed material was attributed to diminished creep, and, therefore, to less weakening of the test section and less intensification of the stress during the run; the total load on the specimen

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was maintained constant in all cases. Stress, therefore, varied slightly at low mean-stresses, and the variation increased as mean stress was raised. Prof. Haigh considers that "creep may afford a valuable safeguard against fatigue due to pulsating stress. If creep occurs below the fatigue limit, stress concentrations may be dissipated before they can cause fatigue."* This statement can only be true when the creep is limited to small amounts, and is not sufficient to weaken the specimen permanently. Reference to the creep diagrams, Figs. 26-31, and to Table VIII, show that creep continues throughout the endurance tests, and that this creep must necessarily nullify the effects of the initial internal stress.

With mean compressive-stresses, the endurance ranges are much greater than those predicted by Gerber's law; this is mainly due to the fact that creep effects now help to increase the sectional area, and thus to decrease the value of the initial stress and of the stress range. Fractures occur in a plane normal to the axis of the specimen, and these have the general appearance of fatigue fractures; such fractures are obtained even in cases where the stress is compressive at both upper and lower limits.

4. That, in the case of a mild steel, whether annealed or lightly cold-drawn, the grain direction has no appreciable effect on tensile properties other than ductility, or on the Wöhler endurance range. The effect of grain direction on the Izod value is not yet clear.

Hence we conclude that, within the limits of the present investigation, the cold drawing of mild steel—

Increases the tensile strength;
decreases ductility in tension;
increases the Wöhler endurance range, but decreases the ratio $\frac{\text{Wöhler range}}{\text{ultimate tensile strength}}$;
increases the endurance range for direct stresses (Haigh cycle);

* Trans. of the Institution, 1926, vol. lxix, p. 388.

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increases the ratio $\frac{\text{Haigh range}}{\text{ultimate tensile strength}}$ for all values of mean tensile-stresses, but decreases the ratio when the mean stresses are compressive;

decreases the Izod value to a minimum value, but that further cold work appears again to cause an increase;

does not produce a directional effect on tensile or Wöhler properties—for small amounts of cold work.

It emerges, therefore, that cold-drawn mild steel may be used freely under direct and fluctuating stresses, inclined at any angle to the direction of drawing, provided always that the Izod value can be regarded as satisfactory. The Izod value is very considerably reduced by cold drawing, and it may be reduced to a very low value. Researches already quoted show that the Izod value is not necessarily low in cold-drawn steels, and this suggests that the effect of cold drawing on the Izod value should be further investigated. Such effects are little understood, but it is clear that if a satisfactory test result can be ensured, the possibilities of cold-drawn mild steel will be very greatly enhanced.

I desire to express my indebtedness to the University of Glasgow for facilities in carrying out the research; to Dr. Hay, Royal Technical College, Glasgow, for the analysis of the steels; and to Messrs. Bruntons, Musselburgh, for the preparation of dies and material in the form and dimensions desired.

[SUPPLEMENTARY NOTE ON HARDNESS.

The hardness of the material in the annealed and cold-drawn conditions was investigated by the Brinell test and by the Herbert pendulum test. In the Brinell test, a 5-mm. ball and a load of 750 kgms. was used, the load being maintained for 15 seconds. Mean values have already been given in various tables.

Four tests were made using the Herbert pendulum:—

1. *Time Test.* This test measures the natural period of

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oscillation of the pendulum when supported on the ball as a pivot. The standard length of pendulum 0·1 oms., as recommended by Mr. Herbert, was used throughout the tests. This gives a time hardness of 100 on plate glass.

2. *Scale Test.* The scale test is the angle through which the pendulum will swing from a tilted position before all the energy of displacement is absorbed by the rolling action. It, therefore, measures the resistance of the material to deformation by rolling.

3. *Time Work-Hardening Test.* This test measures the induced hardness which the material is capable of attaining as the result of cold working. The induced hardness is the governing factor in determining the resistance of the material to deformation as in machining.

4. *Scale Work Hardness.* This is a measure of the increase of hardness caused by repeatedly rolling the same spot on the specimen.

For a discussion of the various tests, reference may be made to the numerous articles published by Mr. Edward G. Herbert, the inventor of the tester. The object of the present experiments is to record test results in the annealed condition and after various amounts of cold work done by drawing, and to investigate whether there is any definite relationship between the test results obtained from pendulum test indicating work-hardening capacity or effects of cold work, and the percentage reduction of area which the material has already undergone by drawing. The relationship between Herbert time and Brinell tests can also be considered, and the test results, therefore, can be connected with ultimate strength and fatigue tests, since the Brinell test result bears an approximate relationship to those two properties.

The test results throw no light on the effects of cold drawing on the machining properties of the material. The claims of the pendulum to indicate such effects are, therefore, not under investigation. The effects of cold work on machinability are extremely important from the economic point of view, and

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further information on this subject would be of great value.

In all tests, the surfaces were filed and polished to be as flat as reasonably possible; the final polishing was done by 0000 emery cloth, as in the case of tensile and fatigue specimens. Comparative tests appeared to show no decided effect of direction of final polish with respect to the plane of oscillation of the pendulum under those conditions. All surfaces were truly levelled before test, and the standard pendulum length of 0·1 mm. was used throughout.

The *Time Test* is measured by the time required for 10 swings. Traverses were made by the pendulum across a diameter on the end of each test piece, and from side to side on a diametrical plane in a longitudinal test. In the time work-hardening tests, after the original hardness was noted, the pendulum was rocked by hand through two complete oscillations, and the time hardness after such treatment was noted. This gave the induced hardness.

Scale Tests. The pendulum was alternately placed on the specimen with the bubble at 0 and 100, and the travel of the bubble noted when the pendulum had come to rest after release. The pendulum was then rocked by hand to the opposite end of the scale and released, the position of the bubble at the end of the swing being noted. The difference between the original scale-hardness reading and the average of the readings for the next four swings was taken as giving the " work-hardening capacity " for the material under cold working. All tests were carried out in the standard manner as recommended by Mr. Herbert. The results, which are given in Tables XII, XIII, and XIV, appear to indicate that the hardness over the cross-section was fairly uniform. Random readings were, therefore, taken for the various tests—scale and time.

It will be seen from Table XIII that there is a considerable increase of time hardness after the pendulum has been rocked through two complete oscillations. It follows from this that the original time hardness is affected by the initial angle of oscillation of the pendulum. With the softer materials,

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Table XII.

Herbert Time Hardness.

ANNEALED.					COLD DRAWN.			
		Distance from Edge. Inches.	Time Hardness Number.			Distance from Edge. Inches.	Time Hardness Number.
inch Diameter.	Transverse Section.	·038 ·081 ·121	19·12 19·82 19·72	5 per cent. Reduction of Area.	Transverse Section.	·018 ·034 ·094	23·48 23·52 23·77
		·166 ·218 ·268	19·84 19·60 19·72			·119 ·167 ·190	23·44 24·02 24·08
		·334 ·397 ·455	19·00 19·72 19·83			·259 ·361 ·392	23·83 23·78 24·18
		·503 ·547 ·603	19·04 19·59 19·56			·417 ·497 ·515	23·58 23·10 23·74

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COLD DRAWN.

Time Hardness. Masses of Ball. 4	6	8	Mean 2-8	H5/750 B	B T_0^2	Increase of Time Hardness.
28·30	27·40	28·30	27·98	205·8	·364	4·21
29·38	27·21	28·50	28·31	196·3	·361	4·98
27·56	27·15	26·96	26·96	195·1	·364	3·79
28·08	27·92	27·80	27·68	190·4	·364	4·81
26·65	27·00	26·59	26·59	177·2	·365	4·55
26·61	27·30	26·16	26·65	177·1	·359	4·45
25·14	24·31	24·32	24·48	153·5	·350	3·53
25·20	24·38	23·43	24·42	158·0	·351	3·21
24·92	24·12	25·43	24·89	159·8	·361	3·84
24·77	24·51	25·27	24·74	157·9	·351	3·53
24·92	25·11	24·97	24·87	158·5	·355	3·74
24·68	24·45	24·75	24·62	156·7	·350	3·45
25·36	25·26	25·04	24·92	158·9	·354	3·72
24·79	24·43	24·39	24·46	142·5	·354	4·41
24·55	24·20	25·05	24·32	147·3	·351	3·76
23·58	24·10	23·76	23·80	143·5	·345	3·63
24·84	26·28	25·23	25·25	149·5	·346	4·47
24·20	24·34	24·91	24·19	142·0	·355	4·19
25·60	26·24	25·35	25·38	143·1	·356	5·34
24·63	25·33	25·66	24·96	139·2	·346	4·89
24·90	25·33	24·24	24·54	141·4	·339	4·12

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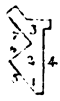
COLD DRAWN.						
MATERIAL.	Scale Hardness after Cold Working with Pendulum.				Mean	Difference = Work-Hardening Capacity.
	2	3	4	5	2–5	
S.I.	52·9	56·0	60·3	61·2	57·6	35·0
	52·3	53·0	61·1	58·1	56·1	37·7
	51·4	51·2	59·8	58·2	55·2	37·0
	55·2	48·5	59·9	61·0	56·2	38·2
	51·1	51·9	60·2	58·9	55·5	38·0
	48·5	51·8	61·8	58·8	55·2	38·8
Flat Bar	46·0	46·5	53·5	52·5	47·1	31·6
	45·5	46·5	52·0	51·5	48·9	32·4
	45·0	45·0	55·0	52·0	49·2	32·5
	44·0	45·0	52·5	51·0	48·1	31·6
	47·0	45·0	52·0	53·0	49·2	33·7
	46·0	46·3	51·7	50·0	48·5	33·8
	45·5	45·0	50·5	52·5	48·4	34·9
	48·6	46·6	58·6	53·9	51·9	38·5
	42·5	38·5	55·0	51·0	46·7	36·2
	43·0	47·0	51·5	52·0	48·4	38·4
	46·0	40·0	57·0	49·5	48·1	36·6
	44·0	45·0	55·0	53·0	49·2	37·7
	51·0	49·0	64·0	54·0	54·5	42·0
	41·0	44·0	51·5	54·0	47·6	35·6
	53·0	47·0	59·0	55·5	53·6	39·1

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especially with the low-carbon flat plate, and profile steel in the annealed condition, consistent results could not be obtained until the initial tilt of the pendulum from the mean position had been approximately standardised. The tabulated results were obtained with initial tilts of four to eight scale divisions. Dr. Benedicks stated* that the lower limit of time hardness for which the pendulum is reliable is about 15. The softer material used was approximating to this condition, and greater difficulty was, therefore, experienced in obtaining consistent results; the difficulty was the greater because the pendulum was applied by hand in all tests. For the softer materials particularly, a standard loading appliance would be of great advantage. The effect of initial angle of swing was not so pronounced with the cold-worked materials.

Some evidence was also obtained that the initial time hardness of the softer materials was affected by the method of preparing the surface; that is, by the amount of cold work done in preparing the specimen. It is obvious that test results from a sensitive appliance, such as the pendulum, must be affected by any hardening treatment to which test surfaces have been subjected. In the tests, all cross-sections were cut by hack saw, filed, and polished with emery of various grades; surfaces were filed, and polished only. Tests made in transverse sections of the S.1 material which had been faced up in a lathe, using very light cuts and polished by emery only, seemed to indicate lower values than those obtained from the sawn and filed specimens. Cold-worked materials were naturally much less affected.

Fig. 36 shows that the test results obtained agree fairly well with Herbert's law that $B = \cdot 36T^2$, where B is the Brinell hardness number and T the Herbert time hardness. The points, however, lie more closely in the straight line $B = \cdot 262T^{2\cdot1}$.

The hardness induced by the pendulum on the annealed material is, as a rule, greater than that induced by cold drawing to the extent used in the present series of tests. The tests indicate that in all cases the cold-drawn material is

* Journ. Iron and Steel Inst., 1924.

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capable of acquiring greater hardness. No definite connection is indicated between the increase in induced hardness and

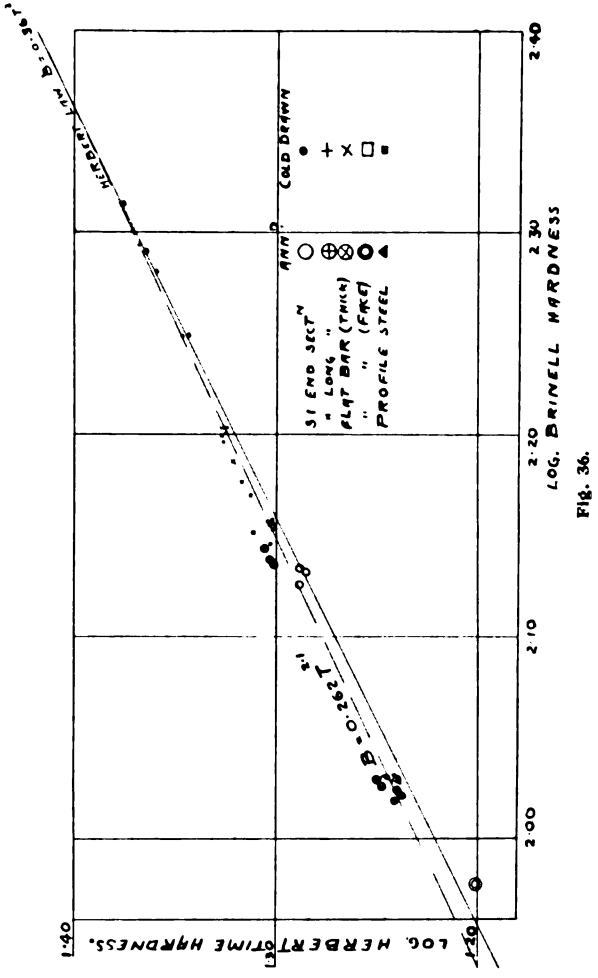

Fig. 36.

the amount of cold work which has been done on the material by cold drawing. The tests made are so few in number and so limited in range that it was scarcely expected that a very

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definite relationship would be indicated. Further experiments of extended scope are being carried out. Much data will require to be collected before the cold-drawing possibilities of a material can be predicted from the pendulum test results.

Similar remarks can be made with respect to the work-hardening capacities as given in Table XIV. It appears that, as might be expected, work-hardening capacity is reduced by cold drawing, but again there is no definite relationship between the cold work done in drawing and the work-hardening capacity before and after drawing. Having regard to the normal variations of materials, it is obvious that conclusions can only be drawn when a vast mass of data is available for analysis. In the next investigation, work is to be confined to one size of annealed material only, and variations in amounts of cold work under different reductions of area in drawing are to be used. It is hoped that by reducing the variations in the material to a minimum, and by increasing the range of cold drawing to a maximum, a definite connection may be indicated.

The Herbert pendulum is an exceedingly interesting apparatus for laboratory investigations and for normal hardness testing on finished articles, but its value to the wire-drawer in assisting him to predict the effects of wire-drawing on a material by means of induced hardness or work-hardening tests has yet to be established.

Discussion.

Dr. A. McCance: The results which Dr. Brown has obtained are not only of scientific interest, but also of considerable practical value. The latter is especially the case in the fatigue limit experiments, since it has always been a matter of uncertainty, in view of the magnitude of the internal stresses which the operation of cold drawing leaves in the steel, whether these stresses may not have a deteriorating influence on the maximum working stresses permissible in parts made from bright drawn bar. Dr. Brown's experiments answer

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that question very convincingly, and show clearly that, even after severe cold-working, the approximate proportionality which exists between the fatigue limit and the maximum breaking stress still holds good. The variations in the factor which have been obtained in the present paper are not greater than the variations which occur in different samples of the same class of steel in the annealed condition. In that connection there is room for further research work into the causes of such variations, since in aircraft work, particularly where the factor of safety is cut down to a minimum, the differences which might exist in batches of the same material when the factor, owing to unexplained causes, varies from ·46 to ·40, are such as to represent a serious diminution in the available surplus of strength.

In boilers in service there are still occasional cases where cracking has taken place in the plates and straps in the neighbourhood of the rivet holes, and this has been proved to be clearly associated with the existence of cold deformation through excessive drifting of the holes or careless workmanship. Since the cold-worked material has now been proved to possess its full fatigue strength, such failures must be a consequence either of the internal stress in the material or its low impact toughness, or both. It is of great interest to find in this connection that the value of the skin tension actually diminishes with the percentage of drawing, as Dr. Brown shows. Since there can be no stress with no cold work, the curve connecting internal skin stress and percentage reduction must pass through a maximum somewhere between 0 and 11 per cent. It would be important to know exactly where this maximum occurs; is it too much to ask Dr. Brown to add a few more points to the curve to complete it in this region? It is probable that this value would correspond with the critical percentage of cold work required to get excessive crystal growth in mild steel on reheating.

Owing to the direct relation also between the Brinell hardness increase and the amount of deformation, this information would be of assistance in helping to determine the causes of

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failure where internal stress is suspected, and would place in the hands of metallurgists a useful means of deciding, through the Brinell test, the position of maximum internal stress.

Prof. B. P. Haigh, D.Sc.: The wealth of data contained in Dr. Brown's valuable paper includes much of practical importance and also of theoretical interest. From the practical point of view, one of the more striking conclusions is the definite increase of fatigue strength that results from cold working (Fig. 19 and page 573). The opposite conclusion, that cold-worked steel is more liable to fatigue than milder, is generally current, and is doubtless based on much practical experience. It cannot lightly be dismissed; nor does Dr. Brown suggest that it should be. The divergence between the two conclusions is important, and has been investigated by Mr. J. S. Wilson and myself. In tests on mild and cold-worked steel strips—described in "Engineering" in 1923—it was shown that rivet holes and other discontinuities of section produce only a moderate loss of fatigue strength in mild steels, because any slight ductile yield dissipates the concentrations of stress which, in a more elastic metal, may produce fatigue when the nominal range of stress is well below the limit indicated by tests on uniform pieces. In a cold-worked steel, the effect of a small opening is so much worse than in a milder steel that the inherently higher fatigue limit may not suffice to give it actually greater strength in practice. When this effect is taken into account, it appears that the true field for cold-worked steels is in wires and ties of uniform section; and that milder steel is safer—in spite of its lower apparent fatigue strength—for plates which are riveted or bolted together, or for other parts with discontinuities of section. It was this aspect of the problem I had in mind when making the statement quoted on page 573.

Dr. Brown's work with stresses varying between unequal values of pull and push makes a very valuable addition to present information on this side of the problem, in which little work is yet available. It appears that the Gerber and Goodman

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formulæ for the actions of such stresses can be regarded as no more than serviceable approximations to the real conditions; and that the following formula proposed by me may be no more than a somewhat closer approximation:—

$$f_s = f_o(1 - (s/u)^n),$$

where f_o is the ordinary fatigue strength for equal pull and push, and f_s is the modified value for a stress that ranges from $(s + f_s)$ to $(s - f_s)$, u being the ultimate tensile and n an empirical index that lies between 1 and 2 in all the metals hitherto investigated. When n is less than 2, this formula indicates that a mean compressive-stress s tends to raise the fatigue limit; and this action is precisely that recorded by Dr. Brown.

The two points noted above are not only of great practical importance, but also of theoretical interest as bearing on the fundamental theory of fatigue failure. I have long urged that fatigue should not be attributed to slipping in the manner which produces ductile strain and is revealed by the formation of slip-bands, but to the action of tensile stress acting more or less equally in three perpendicular directions, as "triple-tensile" stress. Such stress is the opposite of fluid pressure, and tends to produce cracks similar to those which occur in glass and other materials that are strictly brittle. It is suggested that the triple-tensile stress is produced in ductile materials by contractions of volume in small localised zones, owing to the crystallisation of metal that was initially in the "amorphous" state. The opposite and generally current view of the origin of fatigue—that the formation of the crack is due to slipping of the same kind as produces ductile strain—appears to be fundamentally incompatible with the accumulating bulk of evidence that cold working and other kinds of ductile strain always tend to increase the fatigue strength of the metal. The action of triple-tensile stress in fatigue is comparable with that observed in ingots which cool internally after the exterior has become fairly rigid. In many qualities of steel, "clinks" are formed audibly, as internal cracks, during cooling. "Season

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cracking" also, in many cases, may be attributed to the action of such triple-tensile stresses formed by gradual changes of physical state, involving local contractions of volume within the metal. In such cases cracking occurs without slip, even in ductile metals, and it appears to me that triple-tensile is the only kind of stress which can produce cracks without slip. Dr. Brown's evidence that a mean tensile-stress s reduces the fatigue strength, while a mean compressive-stress s tends to raise it, is regarded as evidence that the limiting triple-tensile stress value is reached sooner when the mean stress contributes a tensile influence.

Dr. E. M. Horsburgh, M.A. (Member): Every person interested in the cold working of metal will welcome the valuable researches of Dr. Brown. If anything more is to be done than to express general admiration for such a wealth of recorded observation, it is a little bewildering to select points for special comment. The important results stated in Table II deal with a complicated matter. The stress components at a point are usually taken in three directions at right angles to one another; so in the case of a cylindrical bar they would naturally be radial, tangential to a circle concentric with a right section, and in the direction of a generator. I should have been glad if Dr. Brown had touched upon the effects of these components. I found some little difficulty in understanding exactly what he observed. Thus x_1 and x_n denote "*change* in length due to machining off" the first and nth layers. Was this change of length always an extension? I judge that it was, but this is so important that I think it should be emphasised. As Table II gives the stresses, deduced from what may be called a resultant change of dimension, which is assumed to obey an elastic law, perhaps Dr. Brown might apply some qualifying adjective such as "equivalent" or "apparent" to these stresses.

I venture to suggest an alternative or supplementary way of looking at this part of the subject. When a rod is deformed (drawn) by passing through a die, it is compressed by the die,

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Dr. E. M. Horsburgh, M.A.

and thereafter tends to expand radially. Accordingly it seems reasonable to say that there is a radial tension, which is the partial reaction after the radial compression in the die. The result of this would be a hoop stress in the outer fibres. This again would cause a compressive stress parallel to the generating lines. When the outer skin was machined away, the remainder of the bar, relieved from this longitudinal compression, would extend, *i.e.*, would lengthen in an axial direction. I understand that this axial elongation, which Dr. Brown was able to observe, continued in all cases after the successive machinings, and I should have been much interested in seeing the actual values recorded, as well as those of the stresses deduced by Dr. Brown's method. Hence arose my suggestion of some qualifying word for the equivalent stresses determined by him.

Another particularly interesting section of the paper deals with the effect of grain direction. This gives much valuable information, besides affording confirmation of certain views already held. The observations recorded, of elongation and reduction of area, in the case of specimens at various angles to the axis of drawing, are particularly striking. The ellipticity of the bar on fracture is an impressive feature, and the following is suggested as a supplementary explanation. If we take the granules roughly as spheres, in order to get rid of the difficulties of plane faces, then, after the drawing, they would be lengthened into ellipsoids, with the major axes in the direction of flow. Any one of these, with the usual conventions, would be represented by $\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1$, in which, as the drawing is from $4\frac{1}{16}\times\frac{9}{16}$ to $4\times\frac{1}{2}$ (inches), the intermediate axis has been little changed. Hence the (plane) circular sections would be represented by $x^2-z^2=0$, taking $\frac{1}{c^2}-\frac{1}{b^2}\rightarrow\frac{1}{b^2}-\frac{1}{a^2}$ as the effect of the die. Thus a cylindrical test-piece, formed with its axis in the axial direction of the flat bar, would be predisposed to shear along one or other of these systems of planes. Such slip would give an elliptic right

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section when the specimen fractured. The major axis would be parallel to the major face of the flat bar, and perpendicular to its axis. This ellipticity would be least in a direction of about 45 degrees to the axis of flow, and this seems connected with a certain weakness in rolled sheets. Further, the annealing would reduce the hardening effect, and so encourage flow, which would thus render the elliptic effect more apparent. The ellipticity from a specimen cut at right angles to the axis of flow would evidently be much less than from one cut in the axial direction. In fact, it would only be strongly marked in the axial specimen. The ellipticity too should be detectable, on this hypothesis, in an axial specimen, even at points remote from the fracture. These considerations all seem to agree with Dr. Brown's observations.

Prof. F. C. Lea, D.Sc.: As Dr. Brown says, it is important that we should have a detailed knowledge of the effect of cold work upon materials. Dr. Brown has dealt with tensile tests, repetition tests, and impact tests, and shows the effect that cold work has upon these properties. He does not appear in any way to have considered the modification of properties brought about by heat treatment.

The results of his tests confirm those of previous workers, in that cold work increases the tensile strength, decreases the ductility, increases the Wöhler endurance range, but decreases the ratio of the range of stress to the ultimate tensile strength, increases the endurance range for direct stress (Haigh machine), but decreases the ratio of the range of stress to the ultimate stress when the mean stresses are compressive, decreases the Izod value at first to a minimum, but further cold work causes an increase in the Izod value.

Dr. Brown has also determined the hardness after cold drawing by means of the Herbert pendulum. These tests do not appear to show what I have found in connection with my own work upon the effect of cold drawing on the distribution of hardness through cold-drawn wires. I have found that in very many cases a cold-drawn wire is much harder at the core than

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at the surface. This fact has an important bearing upon the range of repetition stress under torsional stresses, to which Dr. Brown does not refer. The effects of heat treatment at comparatively low temperatures on hardness is of considerable interest. Dr. Brown refers to the hardening that takes place under the oscillations of the Herbert pendulum, but he does not refer to the hardening that takes place when cold-worked material is subjected to repeated stresses.

In a recently published paper* I discussed the effect of heat treatment of cold-worked materials on the limit of proportionality and other properties. I showed that after heat treatment the density, the limit of proportionality, the Brinell hardness, the range of repetition stress, as well as other properties, increase up to a certain temperature of heat treatment which varies with the particular property considered. Raising the temperature of heat treatment beyond certain values causes a diminution in the value of certain properties. The effect on the range of repetition stress is very marked. In a paper† published some time ago, I also showed that the electrical conductivity, as well as other properties, varied with the temperature of heat treatment after cold work. In another paper‡ the effect of repeated shear stresses on wires which have been subjected to cold work and particular heat treatments are considered. Further work since the publication of this paper, using not only spiral springs but also a special machine designed for the purpose, has shown that the range of repetition stress for wires having a tensile strength of as much as 90 tons per square inch, may be no greater or even less than for wires having a tensile strength of 60 tons per square inch. These tests, as well as the results given in the paper just referred to, show very clearly that surface conditions are much more serious under torsional range stresses than under direct or the Wöhler range stresses. This is, no doubt, what may be expected.

* "Engineering," 23rd December, 1927.

† Proc. Inst. of Metals, 1923.

‡ Proc. Inst. of Mechanical Engineers. April, 1927.

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Prof. F. C. Lea, D.Sc.

As a striking illustration of the ineffectiveness of static tests to reveal defects, specimens have been found actually cracking along spirals at 45 degrees under static torsion without of necessity leading to failure, and the wires at much higher torques have failed by shearing on a plane at right angles to the axis. Heat treatment has an important effect upon the range of repetition stress of these wires, but it also very markedly diminishes the ductility as measured by the number of turns of 100 diameters of wire. I hope to publish very shortly a complete account of recent work, in which these points will be dealt with at greater length.

The important points for the moment are:—(1) That for cold-worked material the torsional repetition stress appears to be much more important than direct or Wöhler repetition stresses; (2) that surface defects and internal stresses can be modified by heat treatment; (3) also that many of the properties of the materials can be modified by heat treatment.

One other point of interest to which Dr. Brown does not refer is that a cold-worked material, which has not been in any way heat treated, does not appear to have a fatigue limit quite so definite as when the material has been heat treated. I have found that in the cold-worked condition the fatigue range continually falls from 10 million to 100 million repetitions, whereas when the material has been heat treated at, say, 400 degrees C., the difference of fatigue range for 10 millions and 100 millions is very small.

Mr. J. S. Glen Primrose, A.R.T.C.: The results quoted in the latest piece of exhaustive research work presented to the Institution by Dr. Brown open up several points which appear to be at variance with ordinary experience gained in works' practice; but possibly the further series of experiments projected might bring about a more complete reconciliation of the divergencies.

In the first place, the cold working of metal by drawing it through dies is not exactly similar to other forms of cold work, since the compressive forces acting upon the material

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are all directed inwards to produce flow, whereas in rolling or beating there is always a certain amount of lateral freedom which permits spread to take place, and the forces set up are more confined to one plane of action. A parallel might be drawn to hot forging which may sometimes injure materials if conducted on the open anvil, and yet not do so if the materials are confined in a die, for in this way even cast-iron can be forged into desired simple shapes.

There is undoubtedly reason for suspecting certain so-called "free-cutting" steels of brittleness, since they often contain very considerable percentages of both sulphur and phosphorus (around 0·12 per cent.), whereas both the mild steels used in Dr. Brown's experiments are remarkably low in these constituents, and, therefore, not so liable to be put into a brittle state by cold working.

The values given for the internal stress in the wire which was subjected to varying amounts of reduction are certainly remarkable in showing that this is reduced as the severity of the cold work is increased. It is quite in accord with practical experience that the maximum tensile-stress is not always at the outside skin, but that a heavier drafting leaves less residual stress than light holing of, say, 11 per cent. reduction of area, appears contradictory. Another way of showing the results of differential stressing of mild steel consists of annealing it at slightly above the critical temperature, and then examining the crystal grain size on a polished section which has been suitably etched. In this way it is general to find that practically the whole of the stressing to the critical flow point has been confined to the surface layers of the low reduction wire, whereas a considerably greater depth of the steel has been so affected by the higher reduction of the heavier holing. It is to be hoped that Dr. Brown will carry out the proposed investigation of steels of higher carbon-content as mentioned on page 510, as there are many problems of interest, from the fatigue and failure points of view, arising out of the additional cold work of heading and bending medium carbon steels (say from ·45 to ·5 per cent.) which are being used very extensively

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to-day in the patented form, to produce heavy-duty wheel spokes, as in that case the direction of the crystal grain seems to have a very direct bearing upon the life and usefulness of the steel.

The further rotating-beam tests for fatigue range values of machined specimens of drawn wire are exceedingly interesting, and appear to point to the conclusion that the relief of stress due to the machining has no appreciable effect upon the tensile and endurance strength. No doubt the two qualifications of stipulating a highly ductile material and only moderate cold work are necessary, since with ordinarily produced wire in which the ductility is to a large extent destroyed by considerable cold work, the removal of the surface layers is consistently found to affect profoundly the tensile properties, and also the endurance as measured not so painstakingly as by the Wöhler tests, but by the simpler and quicker ones of bending and alternate torsion testing. The suggestion to take tensile impact tests on unnotched bars is one which I took up some time ago with the makers of the Wöhler machine used by Dr. Brown, and some very interesting exploratory results were obtained, but the matter is now ripe for carrying a stage further in view of the present reported results.

The statement on page 530 that the limit of proportionality is not a fundamental property of a material, and its determination of little importance to the engineer, is hardly likely to meet with general acceptance, unless it is qualified to refer to such material in a severely cold-worked condition, when the determination of this property is actually very difficult, and the results generally obtained open to doubt. In fact, it is doubtful if any true limit of proportionality exists in such a case.

The mechanism by which fatigue failure occurs in a metal is very cleverly expounded on page 544, and perhaps a slight amount of microscopic evidence might have been introduced in support of some of the statements, which are in the main reliable. The most interesting point brought out, however, is that with rising mean stress the phenomena of creep become

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more important than the usual fatigue effects. This should be an important fact in determining the degree of cold work to which a given mild steel should be subjected in order to render it satisfactory for use in conditions of fluctuating stress. The final conclusion that the grain direction has no notable effect on the tensile properties, save ductility, or on the endurance range is remarkable, and seems to be antagonistic to the usual claim set forth that for maximum life in any part to withstand repeated stresses, the so-called fibre must be in the direction of the applied stress and not at right angles to it. An extreme case of this is exemplified in a badly forged crankshaft, in which the failure of the web by a "fatigue" crack is usually attributed to the fibre or grain direction being found to run across instead of longitudinally.

I wish to express my indebtedness to Dr. Brown for his extremely interesting and valuable work recorded in his paper, and although finality in some of the findings may not yet have been reached, a decided step in advance has been made by his carefully conducted research work.

Mr. Edward G. Herbert: I attach considerable importance to some of Dr. Brown's conclusions, particularly those which relate to the effect of cold drawing on the various physical properties of steel as summarised in conclusion No. 4. These are of particular interest in connection with a process for artificially work-hardening the surfaces of metals, with which I am at present engaged. I only desire, however, to comment on the results and conclusions arrived at with the aid of the pendulum hardness tester.

The method of setting forth the results of the time work-hardening test which has been adopted in Table XIII seems open to criticism, namely, that of estimating the work-hardening effect by the average increase of hardness induced by eight passes of the ball. It has been found in practice that metals differ greatly, not only in the degree of hardness they are capable of attaining as a result of cold work, but also in the *rate* at which this hardness is attained. Some metals, for

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instance, attain their maximum hardness at the second or fourth pass of the ball, whereas others require more than 20 passes to harden them fully. Although this difference in the rate of hardening is not yet understood, either theoretically or in relation to metal-working processes, it is undoubtedly a characteristic appertaining to particular metals. It seems desirable, therefore, to set forth the results of this test in such a manner as to exhibit (a) the maximum hardness attainable, and (b) the rate at which hardening takes place. The average increase resulting from eight passes does not necessarily disclose either of these characteristics.

The effect of making work-hardening tests on material which has already been work-hardened by a previous process (as by cold drawing) is a subject which has received some attention, but which requires further elucidation. It is generally found (as in the present investigation) that metal which has been previously work-hardened is capable of a higher induced hardness, as measured with the pendulum, than the same metal in its unworked state. No explanation of this phenomenon is yet forthcoming.

The fact that a process such as cold drawing does not work-harden metal up to its maximum capacity is in accordance with my experience. On the other hand, recent experiments in which measurements were made of the effect of a cutting tool in work-hardening the chips removed, have shown that in general this much more drastic deformation induces a hardness closely corresponding with the maximum induced by the pendulum work-hardening test. In at least two out of a large number of instances, the hardness of the chip was markedly higher than the maximum that could be induced by any number of passes of the ball. This is another anomaly in the little understood process of work-hardening which still awaits explanation.

The final conclusion, that the effects of wire-drawing on a given material cannot yet be predicted with certainty from the results of the work-hardening tests, must be confirmed. No conclusions of a general nature could in any case be drawn

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from an investigation of two or three varieties of steel. It may be remarked, however, that the figures in Table XIII show the materials under investigation to have been abnormal in their work-hardening properties. An ordinary mild steel having an original time hardness of 20, usually work-hardens to a maximum of 30 or more. The increases of hardness shown in Table XIII from 20 to 26, or from 17 to 24, are unusually low for mild steel, and it might be anticipated that metal possessing these characteristics would be unusually amenable to a wire-drawing process.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member of Council): I do not wish to make any remarks about this particular investigation by Dr. Brown. I am quite well aware that he is investigating the effects of cold working in a form comparatively simple to reproduce, but I should like to ask when we may expect that either he or someone else will investigate the effects of the cold working on mild steel practised in shipyards.

Mr. T. McLean Jasper: I have read this paper with considerable interest, and wish to compliment Dr. Brown on a very fine piece of careful experimentation. I will, however, state at the beginning that I do not believe that the internal stresses due to the cold working of ductile steels play any appreciable part in reducing the strength of cold-worked steel. The reason for this belief is as follows:—

In a load-carrying member with initial stresses, we know that the sum of all the stresses in the section is equal to zero, providing no outside load is applied. In Fig. 37, these initial stresses may be represented on the diagram in which the maximum compression in one part of the specimen is shown at point D, while the portion in maximum tension is shown at point C. The maximum strain difference in different parts of the specimen is shown by the distance AB. When such a specimen is loaded, the portion in maximum initial tension reaches the yield point F, while the portion that was originally

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in maximum initial compression is at point E. Because a portion of the steel in the specimen is yielding, having reached point F, the apparent elastic limit will be at E. The measured stress-strain diagram will be similar to that shown by the continuous line. At point G, the whole of the metal is yielding. What was originally at point C is then at H, and what was originally at D is at G. If the load is then released, the initial stresses are practically eliminated. I have checked this out by measuring the initial stresses before and after stressing

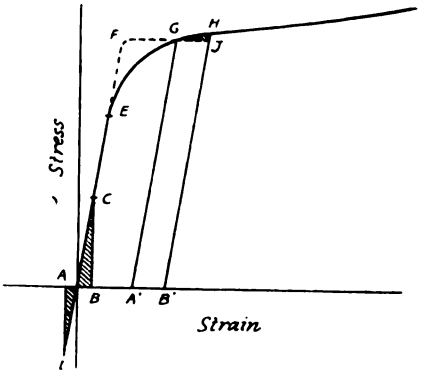

Fig. 37.

in the manner indicated in Fig. 37, both on quenched and on cold-drawn low carbon steel.

I have also studied the question of the effect of initial stresses due to cold forming on the fatigue limits. This was presented at the British Association meeting in Toronto, and is published in "Engineering," September 5, 1924. This shows that, after a relatively few cycles of reversed stress which were near the endurance limit, the initial stresses are very nearly eliminated. It is believed that the degree of relief of such initial stresses by fatigue, depends on the amount which the yield point of the metal being tested is above the maximum stress at which the particular specimen is being repeatedly stressed.

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Mr. T. McLean Jasper.

The question might be asked: What are the damaging effects of initial stresses on fatigue before they have been relieved? The answer is that they are negligible in ductile steels, and need not be considered. This question has been worked through by myself and my associates, and amounts to a statement that, if the metal has been cold worked, it quickly adjusts itself under repeated stressing, and retains the strength properties acquired by cold working. It is not believed, however, that this applies when temperatures above about 500 degrees F. are imposed upon steel. One point might be brought out here indicating that fatiguing of an annealed ductile steel increases the strength. This possibly can be explained on a similar basis to that of cold work.*

I would like to draw attention to Dr. Brown's Fig. 6, and state that I do not believe that these curves show the value of the compression and tension stresses, because they do not conform to the requirement that the summation of all the forces in one direction in a section are zero if no outside loads are applied. His discussion of the value of ductility seems to suggest that it is overrated in importance. I am associated with manufacturing in such a way that I am satisfied that ductility is an exceedingly important factor in engineering. The firm I am with fabricates about 75 per cent. of all the automobile frames used in the American automotive industry, representing an output of considerably over 10,000 frames per day during the busy months. The frames are fabricated cold, and in such a manner that the deformed portion is stronger than the undeformed portion. However, a relatively small difference in ductility may represent a steel which is very undesirable for fabrication purposes.

In the discussion of the range of stress and the conditions surrounding test conditions, it is very difficult to eliminate the special conditions imposed by the testing machine, especially when the ratio of tensile to compressive stress is other than -1. For this reason, it is believed that the effect of strains above

* See p. 29, Bulletin No. 142, Engineering Experimentation Station, University of Illinois.

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the yield point of the metal so modify the stress range imposed by the testing machine that a true condition cannot be plotted nor obtained. Such test conditions do not represent the service conditions, for instance, in a bridge, where the true condition of dead load plus a live weight load gives a definite range of load conditions throughout the life of such a structure, nor does it represent the condition found in many other load-carrying devices, such as railway rolling stock and automobile parts.

Dr. Brown has gone up in his range tests far above the generalised yield point of the material he is studying, and has applied the out-of-balance factor of his loading by a system of springs which, it is believed, modify the applied loads immediately a small amount of yielding occurs in the test specimen. In the Haigh machine, any yielding of the specimen not only modifies the spring load, but also changes the ratio of the gap between the magnets imposing tension and compression. In the Wöhler type of machine, for varying the range, the springs putting on the out-of-balance load are necessarily short, and any small yielding of the specimen tends to bring the stress ratio always nearer -1.

A helpful discussion of the use of the strain-energy relation, it is felt, cannot be made without limiting it to the conditions found within the static yield point of the material considered. In 1924 I discussed* at length this phase of fatigue range testing. Two diagrams were then presented which are partially reproduced here as Figs. 38 and 39. All test results plotted on Figs. 38 and 39 are within the static yield point of the materials tested, and all the values I obtained within the above limitation are plotted on these diagrams.

In the original diagram in the quoted publication, shown here as Fig. 39, were plotted test results on torsion range testing which did not seem to come within the application of the energy relation. The test results omitted here, which were on the original diagram, exceeded the static yield point of the material. These results were obtained on an Olsen-Foster

* Proc. American Society of Testing Materials, 1924, p. 611.

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torsion-fatigue machine which depended entirely on springs for load application. A reproduction of the test results plotted

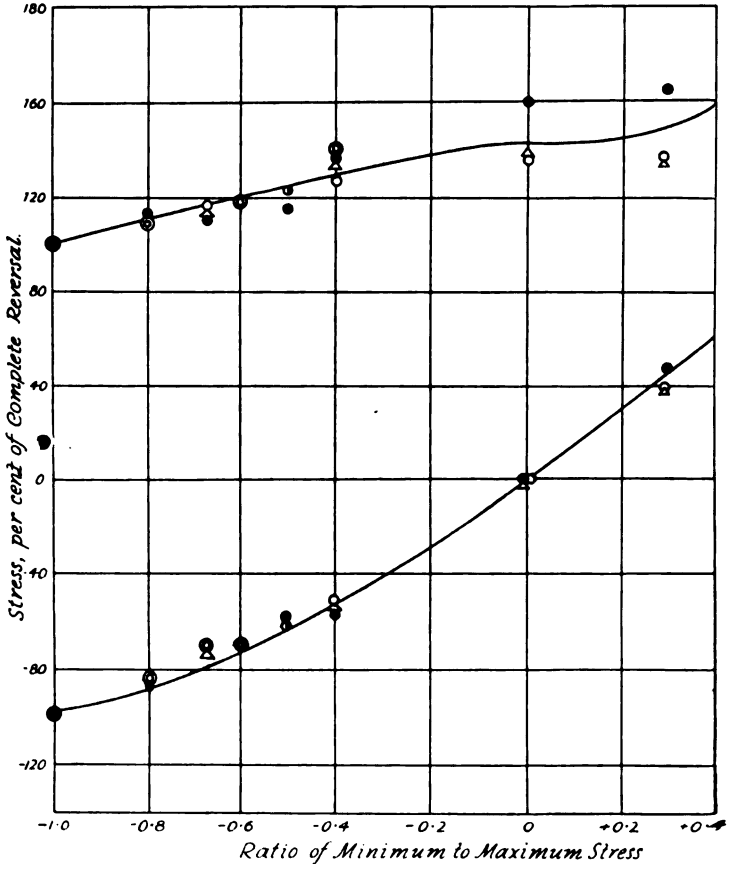

Fig. 38.—Diagram showing the Constant Energy Theory with Experimental Fatigue Results of Flexure Tests Plotted. The Constant Energy Relation is shown by the Continuous Curve.

at this time for torsion, taking particular pains to discover the difference between the stress range and the strain range as the tests progressed, brought out the fact that the stress range was considerably modified, due to yielding of the material,

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as soon as the yield point in torsion was reached, and that the ratio of maximum to minimum stress, after a relatively few cycles of stress were imposed, approached -1. This fact led

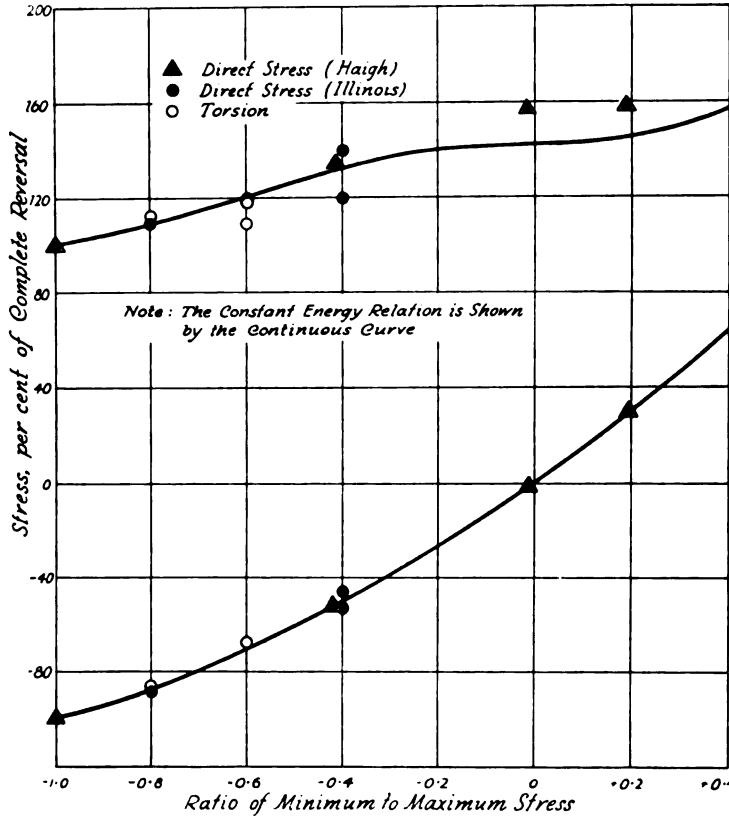

Fig. 39.—Diagram showing the Constant Energy Theory with Experimental Fatigue Results in Direct Stress and Torsion Plotted.

to a careful study of the testing machines for fatigue-range testing, and to the conviction in my mind that all of the machines then available were tarred with the same brush of inaccuracy as soon as the yield point of the test specimen had been exceeded.

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Mr. T. McLean Jasper.

The above data are offered in the spirit of a desire to understand the real facts, and it is hoped that Dr. Brown in his closing remarks will find it appropriate to discuss the points presented here, in the light of his own experimental data and experience with the testing machines which he used. May I also say that when accurate machined parts are needed in service, cold-rolled stock is not a desirable product to use.

In conclusion, permit me to say that I have discussed only the points with which I am most familiar. These points by no means cover the vast scope of Dr. Brown's paper. Although some of the points brought up by him are not conclusively worked through, they open up several avenues of thought directed to the question of discovering the true facts about materials, and especially ductile steels. These steels, after all, carry the bulk of the world's loads, and represent by far the largest proportion of capital investment as well as the largest outlay on which life and limb are dependent.

Dr. R. Hunter (Student): Dr. Brown's results on the effect of grain direction are particularly interesting, and, I think, demonstrate the ability of cold-drawn steel to resist adequately stresses in a direction at right angles to that of drawing. Some designers have in the past been rather reluctant to employ cold-drawn steel to resist such stresses, but I think their doubts will now be dispelled by Dr. Brown's results. It is now fully appreciated that cold work of any kind, whether it be produced by cold setting or drawing, invariably causes embrittlement of the steel. The ductility, as measured by the reduction of area at fracture and the elongation, is sometimes only slightly reduced, but the Izod value generally suffers a very large decrease. This point is well illustrated in Fig. 19. This is certainly a defect which might, in some instances, preclude the use of cold-drawn steel, while, on the other hand, it might be regarded by some production engineers as a desirable attribute, inasmuch as higher cutting speeds could probably be employed.

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Recent research both in this country and in Germany has shown that some steels, even of identical composition, are more susceptible to this embrittling action than others. The ageing propensities also appear to vary from steel to steel, and the outcome of the research has been the production of a non-ageing steel which, I believe, is now on the market. In view of this embrittlement by cold work, I suggest that, with regard to the desirable properties of a good steel enumerated on page 496, to paragraph 4 might be added " . . . and should exhibit the minimum embrittlement by cold work."

It is interesting to note that the Air Ministry now stipulate impact figures on cold-drawn mild steel similar to that used by Dr. Brown in the first part of his paper. The draft specification 3S1 demands the following values, varying with the size of bars:—

	Foot-lbs.
Under $\frac{3}{4}$ inch diameter - -	40
$\frac{3}{4}$ to $1\frac{1}{8}$,, ,, - -	25
Over $1\frac{1}{8}$,, ,, - -	20

I mention these requirements to show that cold-drawn mild steel can hardly be obtained in a reasonably tough condition, contrary to general belief. There is another curious point which crops up intermittently in connection with cold-drawn mild steel. Some bars appear to be reasonably uniform along the length as far as hardness is concerned, but a considerable variation in toughness is sometimes observed. For instance, a 50 foot-lbs. difference between two adjacent notches of an Izod impact specimen is occasionally obtained. This discrepancy is quite outside any variation in the original annealed or normalised bar, and must, consequently, be due either to the pickling or the cold-drawing operation. Personally, I am of the opinion that it is due to occluded hydrogen which has not been completely expelled by the mild annealing subsequent to pickling. In any case, I wonder if Dr. Brown considers the cold drawing itself to account, to some extent, for the observed variations.

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Dr. R. Hunter.

In conclusion, I take this opportunity of congratulating Dr. Brown on his excellent experimental research, and for the able manner in which he has marshalled and presented his enormous number of experimental results.

Dr. Brown: Dr. McCance's suggestion that the percentage reduction of area which gives a turning value on the maximum internal stress curve may probably coincide with the critical percentage of cold work which gives maximum grain growth on reheating, is very interesting, and will be kept in mind as worthy of future investigation. It is likely, however, that the turning value may not be clearly defined.

If the suggestion that internal stress is due to elastic after-working be accepted, the maximum internal stress which can possibly occur is the stress at which slip or creep will again supervene in the material. If the internal stress were to increase at lower reductions of area, and the maximum stress decreases to a minimum of about 32 tons/in^2, it is obvious that the probabilities of creep are increasing, and it, therefore, seems reasonable to expect that the internal stress will not rise greatly above the figure recorded, and that the internal stress curve will probably be somewhat flat on the top, with no clearly-defined turning value.

Failure of the boiler plates mentioned is probably due to reduced impact toughness, together with minute bursting cracks due to the excessive drifting. It is probable that the material would retain sufficient ductility to prevent steady stresses becoming really dangerous, but if reduced impact toughness and minute cracks co-exist the material may be in an unsafe condition.

Prof. Haigh shows that such rivet holes and other discontinuities produce only moderate loss of fatigue strength in mild steels, because slight ductile yield dissipates the stress concentrations, whereas such conditions are more objectionable in cold-worked steels. He concludes that annealed steels may be safer in practice in spite of lower apparent fatigue strength. Ductility is the safety valve which permits of the relief of

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stress where concentrations occur, whether due to discontinuity, internal stress, or other causes. If the ductility is insufficient, the safety valve does not function properly, and a dangerous condition may arise. Under such conditions, Prof. Haigh's statement is undoubtedly true, but the difficulty in defining when ductility is sufficient remains, and this matter requires further investigation. In the present tests, even at the highest reduction of area, ductility is still fairly good, and the rising value of the Izod figure indicates reasonably safe material. On the other hand, the tendency which such bars have to break close to the wedge grips, when tested in tension, on their full diameter, indicates a deficiency in resisting stress concentration there. This only emphasises the desirability of impact tests on bars of full diameter. Prof. Haigh's "triple-tensile stress" theory is interesting, but the present experiments throw no light on this matter; the results record effects of cold working, and do not deal specifically with causes of failure under stress.

Dr. Horsburgh enlarges on the triple nature of internal stress; his discussion is rational, and follows directly from the assumption that the internal stresses are due to elastic after-working. That the hoop stresses exist is obvious from a study of cold-drawn bars which crack subsequently to the cold-drawing process. Such cracks are generally parallel to the axis, and frequently run the entire length of the bar. Radial and tangential stresses have secondary effects in a direction parallel to the axis of the bar. These secondary effects were neglected in calculating the internal stresses. The figures given are based on the assumption that any changes in length are due to primary stresses only. As stated in the paper, the method adopted for determining the internal stresses is probably not capable of a very high degree of accuracy. Dr. Horsburgh elaborates one of the sources of error in the approximate calculations. His explanation of the shape of the fractures obtained from the flat bars is very interesting, and it is borne out by observations on the specimens. The ellipticity was very decided, on the annealed material par-

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ticularly, throughout the entire length of the test specimen, up to the commencement of the radii at the enlarged ends.

Prof. Lea's recent investigations, which show that with cold-worked materials fatigue effects, with repeated or reversed torsional stresses, are of much more importance than repeated direct or Wöhler stresses, are very important, and further results are awaited with interest. The field of investigation into the effects of torsional stresses has been much less explored, and further results will be very valuable. The continual fall in the fatigue range with cold-worked materials for very large numbers of cycles has been noted by other experimenters also. In the present series the aim was rather to compare the materials on a basis of a practical endurance range, which was defined arbitrarily as the range for a life of about 12×10^6 cycles. Even with this limited scope, the experiments show that the continual fall in the range number of cycles curve is even more marked with high mean-stresses.

Prof. Lea's investigations on hardness of wires indicate that the cores were much harder than the surface layers, and that this had a profound effect on the strength under repeated torsional stresses. This difference in the distribution of the hardness may be due to a mass or to a dimensional effect.

Mr. Primrose refers to a similar point in discussing the effect of cold work on internal stress. With light drafting, investigation of grain growth shows that cold work is confined to a comparatively slight depth, whereas a considerably greater depth of steel has been affected by heavier drafting. This seems to indicate that the effects noticed will be affected by the dimensions of the rod and by the amount of the cold work, and that bars of relatively large diameter under relatively light cold-working will give different results to those obtained on smaller wires under, probably, greater percentage reductions of area.

Mr. Primrose considers the statement that heavier drafting gives lighter stresses than those obtained by lighter drafting, contradictory. This is not so if the explanation of elastic after-working be accepted. When the material leaves the die it is

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relatively plastic, and may be straightened with comparative ease. After ageing, there is more spring or elasticity in the material, and the straightening process is more difficult. The plastic material cannot be highly self-stressed, nor need it transmit high stresses. Thus for 11 per cent. reduction of area, the plastic material is required to transmit a mean stress, due to the draw-bar pull, of 7·48 tons/in^2. With a somewhat plastic material, the stress is probably reasonably uniform over the cross-section. If this drawing stress be compared with the maximum internal stress, after ageing, of over 26 tons/in^2, it would appear that the internal stress is due to elastic afterworking or elastic recovery, and anything which impairs elastic recovery, say excessive cold work, would necessarily result in lower internal-stresses.

Mr. Primrose does not agree that limit of proportionality is of little importance to the engineer. The engineer evidently considers it of little importance, since he seldom attempts to find it experimentally. Slip is an irreversible operation, and the limit of proportionality is the stress at which the first slip occurs. This stress, in general, cannot be detected, and it is unimportant. The limit of proportionality, as found experimentally, is the stress at which the summation of the minute slips reaches a value which can be measured by the extensometer used. This obviously depends on the instrument and on its user. The engineer requires to know that the departure of the stress-strain curve from the straight line assumed in his calculations is not sufficient to invalidate his conclusions materially. Within those limits, the form of the stress-strain curve is immaterial to him. It appears to be obvious that in a crystalline material, which may be stressed in any direction, some of the cleavage planes will be parallel to the direction of the applied stress, and slip on such planes must occur at relatively low stresses.

Mr. Primrose's suggestion that grain directional effects will be found to be of greater importance with higher carbon steels is probably true. In the present case, the material used, a highly ductile mild steel lightly cold-worked, showed no very

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decided directional effects excepting on ductility. Even in the present case the results were surprising and unexpected, and in some respects disappointing, since it was confidently anticipated that a directional effect would be noticeable. The only other directional effect indicated was in the Izod values, and in this case the effects were even more unexpected.

Mr. Herbert criticises, probably with reason, the method of estimating the effect of work-hardening by the average increase of hardness induced by eight passes of the ball. This method was adopted because successive passes seemed to produce practically no effect. In no case were more than 12 passes used, and it is noted for future use that some materials require 20 passes or more to develop their full work-hardness. It is interesting to note that Mr. Herbert has also found that cold drawing does not work-harden the material up to its maximum capacity. No doubt much interesting data will yet be forthcoming connecting work-hardness, as induced by the pendulum, with that induced by cold drawing, but conclusions can only be drawn when a great mass of data is available.

Mr. Riddlesworth's contribution to the discussion took the very practical, and desirable, form of supplying some material, cold worked in the shipyard, for a preliminary investigation. It is regretted that results cannot be obtained in time to be incorporated in the paper, but the experiments may be of great value in indicating a suitable field for further research.

Mr. Jasper's contribution to the discussion is exceedingly interesting, and it is gratifying to find that an authority of international reputation, such as Mr. Jasper, is in substantial agreement with many of the conclusions expressed in the paper. The statement that a piece of material fails when the sum of the stresses due to internal and external loads exceeds a specified value for the material, is so commonplace, and the statement that internal stress has little effect in causing failure in a ductile material, so contradictory, that it is of interest to have this opinion confirmed by other experimenters. Mr. Jasper's explanation is lucid and con-

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vincing as applied to annealed materials which show fairly definite yield stresses; cold-worked material generally shows no definite yield, and the action he describes commences at stresses greatly below those which would be recorded as yield stresses under normal conditions of commercial testing. The action is quite definite at stresses recorded as 1st creep in Table III. His diagram, Fig. 37, would not be so convincing if drawn for such a steel; the points GH would lie on a steeper portion of the curve, and would represent stresses which show a much greater difference. In such cases, the relief of stress, due to slip, is probably greater than would be indicated by the ratios of the stress intercepts of DC and GH in the two cases.

It is also interesting to have the opinion confirmed that comparatively few cycles of reversed stress are sufficient to relieve any internal stresses present in ductile materials. Internal stresses are, therefore, relatively unimportant, given sufficient ductility in the material and a rate of loading or duration of test which permits of internal adjustments taking place. With brittle materials, or with shock tests, the statement is not necessarily true. Tensile impact tests on full-sized specimens are very desirable if further light on this matter is to be obtained; notched-bar or machined test specimens are unsatisfactory, as the machining necessarily relieves the internal stresses. I agree that the curves in Fig. 6 do not show the stresses exactly. No great accuracy is claimed for the method, and in the discussion it is shown that secondary stresses, radial and tangential, have been neglected. An exact balance could only be expected when all effects have been considered. The importance of ductility is overrated by many engineers, but my remarks in discussing this subject were stated to apply to cases where it is not desired to subject the material to further cold-working operations. The operations mentioned by Mr. Jasper obviously do not come within this category, and ductility is essential if the cold fabrication is to be carried out successfully.

Mr. Jasper's criticisms of the effects of yield in the Haigh

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machine are not quite valid. Any yield on the specimen undoubtedly affects the spring position by an almost infinitesimal amount and the air gaps, and, therefore, the stress cycle, by a relatively much larger amount; but this condition is at once indicated, by an out-of-balance current, on the differential ammeter, and the air gaps are equalised by altering the position of the upper end of the specimen. The amount of this alteration is a measure of the yield or creep. The loads, initial and pulsating, are, therefore, restored to their initial values, and the effects of such yields are negligible unless the machine is left unattended and is allowed to run in an out-of-balance condition for some time. In the experiments under review, the machine was closely attended to minimise such effects. It is true that each type of machine imposes its own stress conditions, and that results from different types are not strictly comparable. The effects are largely due to the varying forms of the stress waves, and to the varying distributions of stress intensity over the section, depending on the type of loading.

It is agreed that the strain-energy relation can only be conveniently discussed, on a mathematical basis, on the assumption of proportionality of stress to strain. If the stress limits exceed the stress at the limit of proportionality, the strain-energy relation becomes a function of the form of the stress-strain diagram for which no simple expression can be found. The experiments described were carried out at stresses far exceeding the proportional limits, and, having regard to the varying properties of annealed and cold-worked materials, it is rather surprising that the points grouped themselves so closely to a straight line as in Fig. 25, but not surprising that the equation to this line should differ considerably from the equation predicted by the strain-energy hypothesis, assuming proportionality of stress to strain.

I am in agreement with most of Dr. Hunter's remarks regarding the Izod test. It is clear that the property which is most likely to be adversely affected by cold work is the property which is revealed by the Izod test. The Izod value is

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frequently, but not necessarily, low in cold-worked steels, and if the result of the Air Ministry Specification is to increase our knowledge of the effects of cold work on Izod values, and thereby to ensure that the cold work will be so applied as to have the minimum embrittling effect, greatly increased use of the material will inevitably result, and only then will the full possibilities of this method of manufacture be fully exploited. The values required by the new draft specification are higher than those generally obtained; they will accordingly be the subject of much criticism, and are likely to cause considerable trouble to manufacturers until the effects of cold work on the Izod value are more completely understood.

Dr. Hunter's remarks on the suitability of cold-worked material to be stressed in any direction must be accepted with some reserve. Further investigation is required before all doubts are dispelled. In the present case, a low-carbon steel was used, and this was only slightly cold-worked. These conditions, while typical of many practical cases, do not develop the full effects of grain direction, and experiments with higher carbon steels and heavier drafts may modify the conclusions deduced from the limited scope of the tests.

In conclusion, I desire to thank all who have contributed to the discussion for their helpful criticism, and for their suggestions for further investigations.

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TELEVISION.

By JOHN L. BAIRD.

6th March, 1928.

THE problem of Television consists in converting light into electrical impulses at a transmitting station; transmitting these impulses to a receiving station, and there converting them back into light.

An image of the object transmitted is divided by an optical apparatus into a great number of little sections, and these are projected in immensely rapid succession upon a photo-electrical cell. This cell generates a current proportional to the intensity of light falling upon it, so that an undulating current is transmitted to the receiving station, the intensity of the current at any instant representing the brilliancy of the area projected upon the cell at that instant.

At the receiving station the undulating current controls a spot of light moving over a screen exactly in synchronism with the image over the cell, this light being bright at the high light and dim at the half-tones. The whole process is repeated every sixteenth of a second, so that, due to persistence of vision, the image is reproduced instantaneously.

The first problem which arises is to devise apparatus which will enable the image of the transmitted scene to be traversed over the cell. Within certain limits, this is a comparatively simple matter. Fig. 1 shows an apparatus which illustrates the problems involved, and also the limitations which arise in any simple form of exploring device. It is the apparatus used in my early experiments, and consists of a disc B containing 16 lenses arranged in staggered formation. As this disc revolves,

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each lens causes an image of the object being transmitted to traverse the light-sensitive cell, and as the lenses are staggered, a different strip of the picture traverses the cell for each lens. It will be obvious that only 16th strips could be transmitted were the disc used alone, but by using a spirally-slotted disc D, which is joined to the shaft of the lens disc, any number of strips can be obtained by revolving the lens disc faster, the limiting factor being the mechanical strength

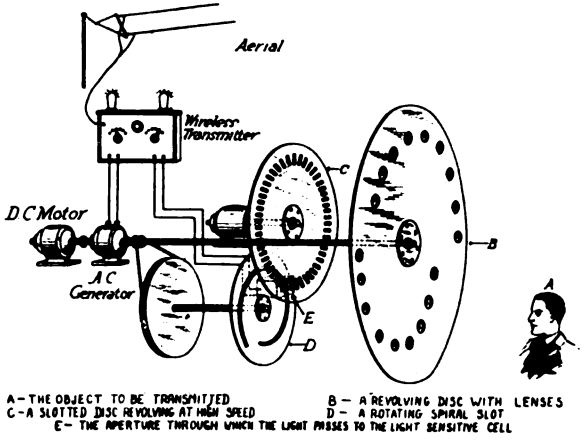

Fig. 1.

of the lens disc. The possible limits of such a disc are reached at a speed of about 2,000 r.p.m., so that it will be seen that a device of this kind is limited to a comparatively simple picture.

In the first experimental efforts this point did not arise, the trouble being not to get the machine to run fast enough, but to obtain a sufficient reaction from the light-sensitive cell with the exceedingly small quantities of light available.

In transmitting a living scene, the problem is entirely different from the transmission of a transparency or cinematograph projection, for where the actual scene is concerned we are dealing not with transmitted light but with diffusely reflected rays, and the light available is infinitesimally small.

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When it is remembered that the whole light reflected back from the human face is not equal to the direct rays of a candle, and when it is understood further that this light only falls upon the cell for an infinitesimal period, the difficulty of the problem will be apparent. The obvious course was to increase the brilliancy of the illumination, but a limit to this was naturally soon reached, and even illuminating the scene with the highest intensity available, the light obtainable was insufficient to give good reaction from the light-sensitive cell. With extra high intensity of illumination, a further limit was that the person whose image was being transmitted was unable to withstand the dazzling brilliancy and the heat accompanying the light.

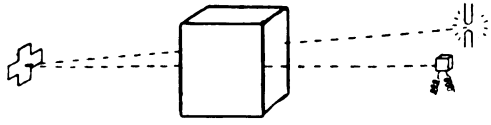

Fig. 2.

Fig. 2 illustrates a device to overcome this difficulty. The illustration is taken from a patent specification of mine, but I may say that the device is not now used by me, as, although it offers a solution to the light problem, it is very restricted in its application, and I preferred to tackle the problem in another way by increasing the sensitivity of the light-sensitive device. The light-spot method consists of traversing over the object a spot of light of intense brilliancy. As this spot of light is continually moving, it does not burn or dazzle the person being transmitted.

The optical effect is shown in the diagram, and when the spot method is used with the device illustrated the optical efficiency is very high. It has, however, the obvious limitation that only an object coming within range of the light spot can be transmitted, and, furthermore, it cannot be used with normal illumination. For example, a scene illuminated with daylight cannot be transmitted. I, therefore, increased the

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delicacy of the light-sensitive device and, some two years ago, in January, 1926, using apparatus similar to that shown in Fig. 1, I was able to obtain transmission of a human face.

I will now return to Fig. 1, and will discuss some of the problems which arose in obtaining a finer grade image. Firstly, the speed of the disc B gives a definite limitation, mechanical consideration preventing us from revolving this disc beyond a certain fixed speed. This difficulty arises with all forms of mechanical exploring devices. It is not, however, insurmountable, and I will illustrate two methods of overcoming it. The first device consisted of what I have termed an optical lever; Fig. 3 shows the arrangement. An

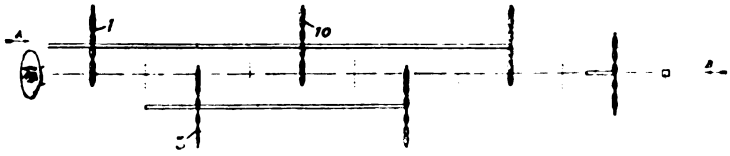

Fig. 3.

image of the object is first caused to traverse a screen by a rotating lens disc 1, and is then caused to traverse a second ground glass screen by rotating the lens disc 3. The image of the second glass screen in turn goes through the same process by means of the lens disc 10, so that any desired speed of traversal may be obtained without increasing the rotational speed beyond desirable limits. The ground glass screen may, of course, be omitted.

Another alternative is to transmit the image in a series of zones. This offers a simple and straightforward way out of the difficulty, but unfortunately demands a separate channel of communication for each zone.

At the receiving station, the problems arising are to obtain a light source of sufficient intrinsic brilliancy and sufficiently rapid in action. I have used various forms of glow discharge tubes with satisfactory results, but as the grain becomes finer the difficulty arises of obtaining sufficient illumination, particularly when reproduction on a large screen is desired.

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A method of producing an image of a large and brilliantly illuminated kind is given in Fig. 4. This shows a screen consisting of a bank of light sources, supplied from commutators revolving in synchronism with the exploring device at the transmitter. As each area of the picture is represented on a single lamp, and the commutator must have one section for each lamp, it is obviously very complex; but it does indicate a method of obtaining a picture of any degree of brilliancy and any desired size.

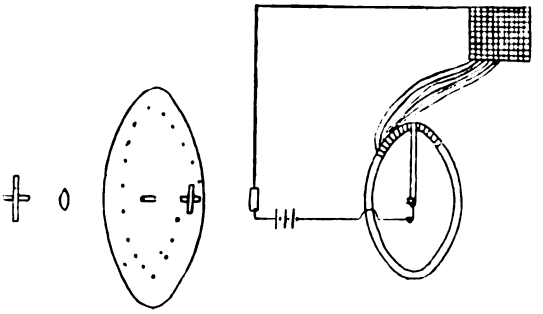

Fig. 4.

The situation at present is that it is possible to transmit, with a fair degree of success, images of restricted scenes such as head and shoulder views of single persons, and these can be transmitted over considerable distances with the use of a comparatively simple receiving apparatus.

The greatest distance transmitted by telephone wire is between London and Glasgow, and a quite simple receiving apparatus was used for this demonstration, the principles of the apparatus being similar to those indicated in Fig. 1. The size of the apparatus is shown clearly in Fig. 5, a reproduction of a photograph taken during the demonstration.

With regard to the distance transmitted by wireless, we have recently succeeded in transmitting between London and New York. The results are still somewhat erratic, due to atmospherics and fading, but they are sufficiently clear to enable recognisable images of living persons to be sent. Our

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television transmitter is situated at Long Acre, in the west end of London, and the television signals are transmitted from Long Acre to our wireless station at Coulsdon by telephone wire. At Coulsdon the signals are amplified, and used to modulate the carrier wave of a two-kw. transmitter operating on a wave length of 45 metres. Reception takes place at Hartsdale, a suburb of New York, and return communication is established by means of morse signals sent out from a small transmitter at Hartsdale.

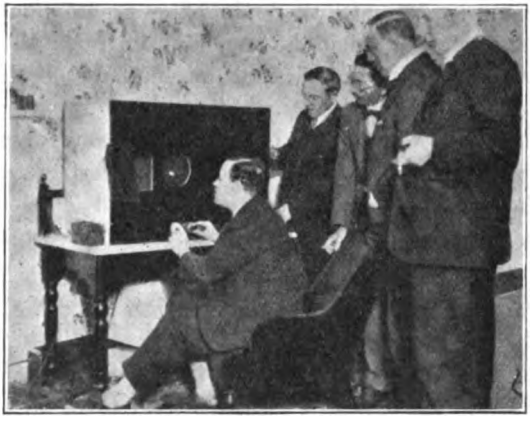

Fig. 5.

Before going further, I should like to say a few words on the development of television, which I have termed "noctovision," or "seeing in the dark." By using infra-red rays in place of light, it has been possible to dispense with the necessity of illuminating the object, so that using a combined television receiver and transmitter and the infra-red rays, it has been possible to construct an apparatus which sees in total darkness.

The infra-red rays have the property of penetrating fog some 16 times better than light rays. In fact, it has been shown with this apparatus that objects surrounded by a fog, quite impenetrable by the human eye, are quite visible on the nocto-

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visor. Work is now proceeding on the lines of increasing the range of this apparatus with a view to applying it to navigation.

A further development, and one which is, at present, perhaps more of a scientific curiosity than a commercial proposition, is the phonovisor. To explain the action of this apparatus, I may state that, in transmitting by television, an image is first of all transformed into undulating electrical impulses, and these impulses can be heard on the telephone as sounds. In phonovision these sounds are permanently recorded on a gramophone record, and by playing the gramophone record into the televisor the original image is seen upon the screen. This device might have had considerable commercial possibilities if the cinematograph had never been introduced, but unfortunately the cinematograph serves the same purpose as the phonovisor, and does it in a much more perfect fashion.

Phonovision has a possible advantage in that it gives a more compact method of recording and reproducing vision, and is a method which is very suitable for combination with the gramophone. We are working now upon the phonovisor with the object of producing a gramophone which will show, in a simple way, an image of the person whose voice is being heard simultaneously with the reproduction.

With regard to the future of television, it is not easy nor perhaps wise to make prophecies, or to lay out the exact lines along which the art will develop. It will be realised, however, that television, on the method I have outlined to-night, is considerably more complex than telephony, and such being the case, cannot reasonably be expected to develop so quickly or extensively. We live, however, in times of unprecedented and continually accelerating scientific progress, and I think I am safe in saying that we will not have long to wait before television becomes a definite factor in commercial life, and takes its place as one of the recognised, and I believe the most important, methods of communication.

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SOME TECHNICAL PROBLEMS OF BROADCASTING.

By Capt. P. P. Eckersley.

12th March, 1928.

Abridged.

Some of the first efforts in broadcasting were made at Chelmsford, in England, where the Marconi Co. erected a 15-kw. station working on a long wave-length. Practically simultaneously, transmissions took place in America from the Westinghouse Manufacturing Co.'s works at Pittsburgh, Pennsylvania. The English transmissions were brought to an abrupt close, because they were said to interfere with other services.

During 1919-22 the Americans' system forged ahead on the basis of private enterprise. Their stations were erected to give programmes which, in one way or another, advertised some particular product. There were two ways of doing this. One way was for the station to be erected by the manufacturer or retailer of a particular product, and the other for a broadcasting company to erect a station and sell time to would-be advertisers. Thus, typically in the latter case the Attwater Kent Co. buys perhaps two hours of time from the National Broadcasting Co., and during that time pays for a concert by a well-known symphony orchestra, the sole advertisement to the Attwater Kent Co. being an announcement at the beginning and end of the concert that the concert has been arranged and paid for by that company.

In 1922 the Radio Society of Great Britain, representing the amateur movement, petitioned the Postmaster General for a broadcasting station, and obtained permission to erect one at Writtle, near Chelmsford. This station started

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transmitting in 1922, and gave regular concerts for half-an-hour a week, but it must be understood that these transmissions were only for a limited clientele, and that no definite listening system was involved.

At the end of 1922 British wireless manufacturers pooled their interests in a central public utility concern called the British Broadcasting Co. The capital of this company could only be subscribed by *bona fide* British manufacturers. Because their companies had subscribed relatively large sums, the managing directors of six large manufacturing firms became the directors of the British Broadcasting Co. The Postmaster General ruled that the interest on the capital subscribed should not exceed 7½ per cent. The company's revenue was to be a portion of a licence fee paid by anyone who was equipped to listen to the programme given by the company.

Although technically a commercial company, the policy of the Board of the British Broadcasting Co. was to make the operations of the company essentially those of a public service, and whereas arrangements might have been made by which the reception of programmes was a matter of buying an expensive set, the whole object of the company was to make wireless reception as simple as possible, and to have as many subscribers to the service as possible.

In 1926 the company was dissolved, and a corporation formed in its stead. Every member of the staff was retained by the corporation, and the operations of the service were continued, the change being a constitutional one involving simply a change in the directors. The British Broadcasting Corporation is thus given by Royal Charter a monopoly to do broadcasting in Britain, and it only continues to be a public utility corporation. From a technical point of view, it will thus be seen that the objects of the technical directorate of both company and corporation are to give a service which is as uniformly excellent throughout the country as possible, at the same time paying due regard to majorities.

The first basis of the technical service was to erect 1½-kw

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stations at Aberdeen, Glasgow, Manchester, Newcastle, Birmingham, Bournemouth, Cardiff, London, and later on, a station at Belfast. Due to interruption from electrical disturbances of all sorts, it was found that the true service area of these stations was contained in a circle around the station of roughly 30 miles' radius. Outside this area, the weakness of the signal compared to the disturbance made broadcasting impossible to receive without interruption. The circles of 30 miles round the towns mentioned contained only 50 per cent. of the population, and the next move was to fill up the areas not served by the main stations. This was partially done in 1924 by the erection of several small stations in areas outside the service areas of main stations, the areas chosen being Dundee, Edinburgh, Hull, Leeds, Sheffield, Liverpool, Nottingham, Plymouth, Stoke, and Swansea. The addition of these "relay" stations to the main stations brought about 65 per cent. of the population within the service area of one programme. In order to fill up the areas still unserved—areas mainly rural—a high-power long-wave station of 25 kw. on 1,600 metres was erected in the centre of England.

By the combination of main, relay, and long-wave high-power stations, about 85 per cent. of the population were brought within the service area of one programme. The object of the long wave was, on the one hand, to have a transmission far removed from the wave lengths used by ship and shore stations, which interfered badly with the medium-wave broadcast, and on the other hand, to use a frequency which gave a slow attenuation of energy from the central station, and thus to be able to fill up areas as far apart as Land's End and the north of Scotland. It will be seen from this brief summary that, by a combination of different types of station, a service was arranged which could be considered satisfactory from a majority standpoint.

Unfortunately the service to-day is not as good as when it was first installed, because many other nations have built up similar systems, and these stations are producing interference in the service areas of British stations. It is a fact that if

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any station of practically any power working in Europe is not removed by a sufficient frequency difference, it will interfere with any other similar station. This trouble was foreseen in 1924, and the British Broadcasting Co. arranged a conference with the other European organisations concerned, which resulted in the formation of the Union Internationale de Radiophonie.

The problem confronting the Technical Committee of that body was simply that there were 100 channels available for broadcasting, and some 150 stations were already working, while many more were in course of construction. It was decided to make use of a compromise in order that some, at least, of the stations should continue to have uninterrupted service areas. The basic idea of the plan called the "Plan de Genève" was the repartition of wave lengths in Europe, so as to allow 84 exclusive waves among European countries and to share the remaining 16 among surplus stations. Stations sharing waves have considerably restricted service areas, but the scheme proposed ought at least to guarantee free channels to 86 stations. According to the Plan de Genève, Britain finds herself with 10 wave lengths and 22 stations.

The rapid growth of broadcasting and the somewhat opportunistic way in which it has been built up throughout the world, means that at the present time the distribution for a national service must be reframed, with the idea of abandoning the international shared wave and using only the exclusive wave. This means that the basic principle for redistribution for a national service must be in terms of fewer stations and higher power.

The British Broadcasting Corporation has promulgated a scheme called the Regional Scheme based on the use of fewer stations and higher power, and with the object of giving to every listener an alternative programme. The best way of giving alternative programmes is to radiate the two programmes from the one point when the service areas of the stations will be coincident. Thus the Regional Scheme, on

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the basis of 10 exclusive waves, in principle involves five centres of distribution using two wave lengths each. Naturally, the stations must be of much higher power than has been visualised heretofore. Experimental beginnings have been made by the erection of a high-power medium-wave station at Daventry, which, for 100 miles' radius at least, has a service area coincident with that of the long-wave station, and over this area gives an alternative programme. It is hoped, when permission is forthcoming, to install, in various centres, twin wave-length high-power stations, as visualised in the scheme outlined above.

A further important development arises in connection with the interlinking of national systems. So far, a scheme for redistribution of national services has been outlined. When this is complete, the next step will be the interlinking of national broadcasting services, so that a programme anywhere in the world can be given from local aerials. In a continent such as Europe this presents no difficulties, the ordinary telephone network being sufficient to pick up a programme at any point, and distribute it from as many stations as wish to radiate it. Experiments have already been made, and British listeners have heard from their local station programmes performed in Belgium and Germany.

The problem of linking together continents separated by a large amount of water, however, is not so simple, because the telephone cable cannot bridge large oceans. It is here that short-wave wireless is expected to play a part. At present, however, the problems underlying the linking of continents by short-wave wireless are so great that no guarantees of service can be given, and it would be unwise at this stage to say that the problem will ever be solved, although experiments made in Britain and America do indicate that in the future a possibly limited service may be given.

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THE DEVELOPMENT OF THE FIAT MARINE OIL ENGINE.

By D. M. Shannon.

20th March, 1928.

It is always an advantage to have a short history of the rise and progress of any particular development that can be filed for future reference. Obviously this affords help in preventing the repetition of a good deal of costly experimental work on ideas already tried and found wanting. At the same time, it is desirable to record the reasons for proceeding along certain lines. Archimedes made a greater relative advance in his time than probably any other investigator in the world's history, and he left behind excellent records of his achievements. Unfortunately, he gave no indication of his methods of reasoning, so that his immediate successors could not carry on from where he left off, with the result that progress in science slowed down enormously after his death. This is a fault that those engaged on modern research should, if possible, avoid.

The object of the present paper is to place on record the various steps leading up to the present-day Fiat engine, and to give, as far as possible, reasons for abandoning constructions that were found unsuitable for marine duty. In the light of modern knowledge much will be self-evident, but an abbreviated outline will no doubt be of use to those embarking on the development of a new engine.

Going back as far as 20 years to the origin of the engine, attention may be called to two points worthy of particular consideration, and by which the evolution of this type of engine differentiates itself from any other. First of all it should be mentioned that, while many builders started the

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construction of marine-oil engines, adapting to the marine requirements their land types by making slight modifications, the Fiat engine was born as a marine engine, and its subsequent evolution was based on sea experience only. For this reason, many of the troubles met by builders of land engines were not encountered. Land engines are very seldom called upon to perform the same continuous duty that is demanded from a marine engine. As a rule they run intermittently, and always work on a level base; but in the early days, when the same motor was placed on a floating platform and subjected to long non-stop runs, unexpected weaknesses very soon appeared. These were mostly due to insufficient bearing surfaces throughout the whole engine, lack of rigidity as affecting maintenance of alignment, and defective cylinder lubrication. There was also considerable trouble on account of inaccessibility, since what can be done in a power station, with plenty of space and facilities for overhauling, cannot readily be accomplished in the confined engine room of a vessel.

In the case of the engine under review, in addition to the fact that it was born as a marine engine, it was originally developed to meet the very special conditions on board submarine vessels, where accessibility and overhaul are much more difficult to accomplish satisfactorily than on any other type of vessel or on land.

At a later date, when the propulsion of surface ships by oil engines was in the development stage, Fiat gave early attention to large marine motors, and the extreme accessibility of the present-day engine can be traced to the difficult conditions under which it was evolved. It should also be noted that the two-stroke engine was adopted at the beginning and has never been departed from, whereas some builders adopted the two-stroke engine as an alternative to the four-stroke engine, and gave up the construction of the latter type at a later date.

The decision to adhere to the two-stroke cycle was based on the following well-known reasons:—

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1. The two-stroke engine develops much more power than the four-stroke for the same piston displacement.

2. A two-stroke engine will develop the same power as a four-stroke one with reduced number and dimensions of cylinders, thus giving a smaller and lighter engine.

3. Larger powers can be developed by the two-stroke engine, without the limitations met with in the four-stroke engine which have recently made builders adopt some compromise in their designs.

4. The two-stroke engine requires no exhaust valves nor complicated cylinder covers to house them.

5. The two-stroke engine gives a far more even twisting-moment for the same number of cylinders.

6. With two-stroke engines, the inertia of the reciprocating masses is balanced at the top dead-centre by the pressure on the piston.

7. For a reversing engine, four cylinders can be used, whereas the minimum number for a four-stroke engine is six.

Within the last few years the whole trend of oil-engine development has substantiated the early faith placed on the final success of the two-stroke type of engine when other builders were sceptical of its success. For instance, in 1922 the production of two-stroke engines was only about 15 per cent. of the total output of all types of oil engine. For motor vessels of over 1,000 tons gross on order in January of this year, more than 50 per cent. of the propelling power will be developed by two-stroke engines. It would thus appear that the present engine is a pioneer in the field of the marine two-stroke engine, and one having a most extensive experience behind it.

It will be interesting to relate the historical steps of its evolution by a short review of the engines built during the periods before, during, and immediately after the war.

The organisation may be considered one of the largest in the world engaged in the internal-combustion engine industry, since actually about 35,000 workers are employed. Its origin dates back to 1899, when it was founded for building not only

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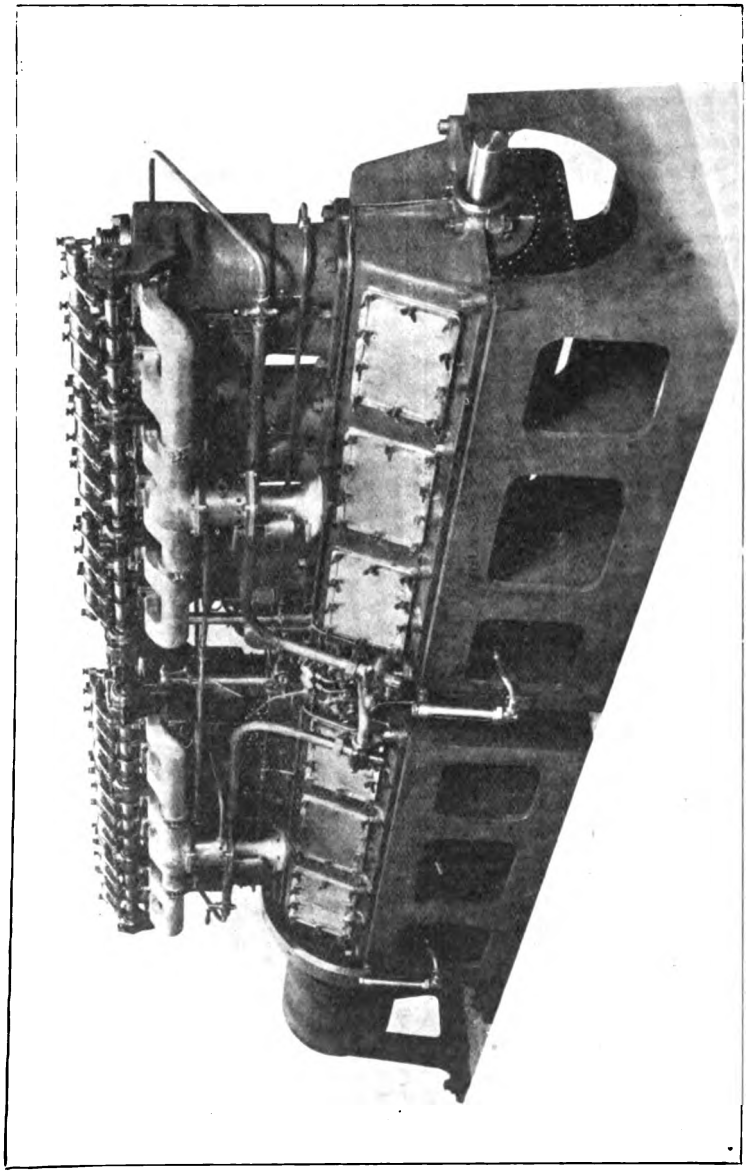

Fig. 1.—Petrol Engine installed on Submarine.

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motor cars, but also internal-combustion engines for all purposes, amongst which marine applications attracted very early attention. In 1905 the firm Fiat S. Giorgio was founded with a shipyard at Spezia, in which were built launches, barges, small craft, and later on submarines of the Laurenti type.

For the construction of marine oil-engines, which in the early days were built in the same works as the motor cars, special shops were secured, and subsequently they were considerably improved, until to-day they constitute the actual works named "Stabilimento Grandi Motori," which are entirely used for the construction of heavy-oil engines of every type, from small auxiliary hot-bulb engines up to those for the propulsion of the biggest vessels.

The first engines of considerable power to be built in these works were of the petrol type for submarines. This would be about the same time as the twelve- and sixteen-cylinder horizontal petrol-engines of the *vis à vis* type were developed in this country by Messrs. Vickers, for British submarines of the A, B, and C classes; but the Fiat engines were of the ordinary straight vertical type with twelve cylinders, each having a diameter of 185 mm. and a stroke of 200 mm., and developing 300 b.h.p. at 750 r.p.m. An illustration of this type is shown in Fig. 1. These engines were of the four-stroke type, and had a weight of about 22 lbs. per b.h.p. The fuel consumption was 270 grammes per b.h.p. per hour, and they were installed in the first submarines of the Italian Navy, type "Foca," each vessel being fitted with three engines and three propellers.

The increasing application of the Diesel engine for land purposes, and the various disadvantages of the petrol engine, such as the impossibility of obtaining big powers without adopting a large number of cylinders, dangers of explosion and fire due to the fuel used, high consumption of a costly fuel, and many other drawbacks, induced the company to consider the use of the Diesel engine for submarines. The problem appeared at once very difficult, as the best types of Diesel engine were bulky and heavy, and quite unsuited for submarine require-

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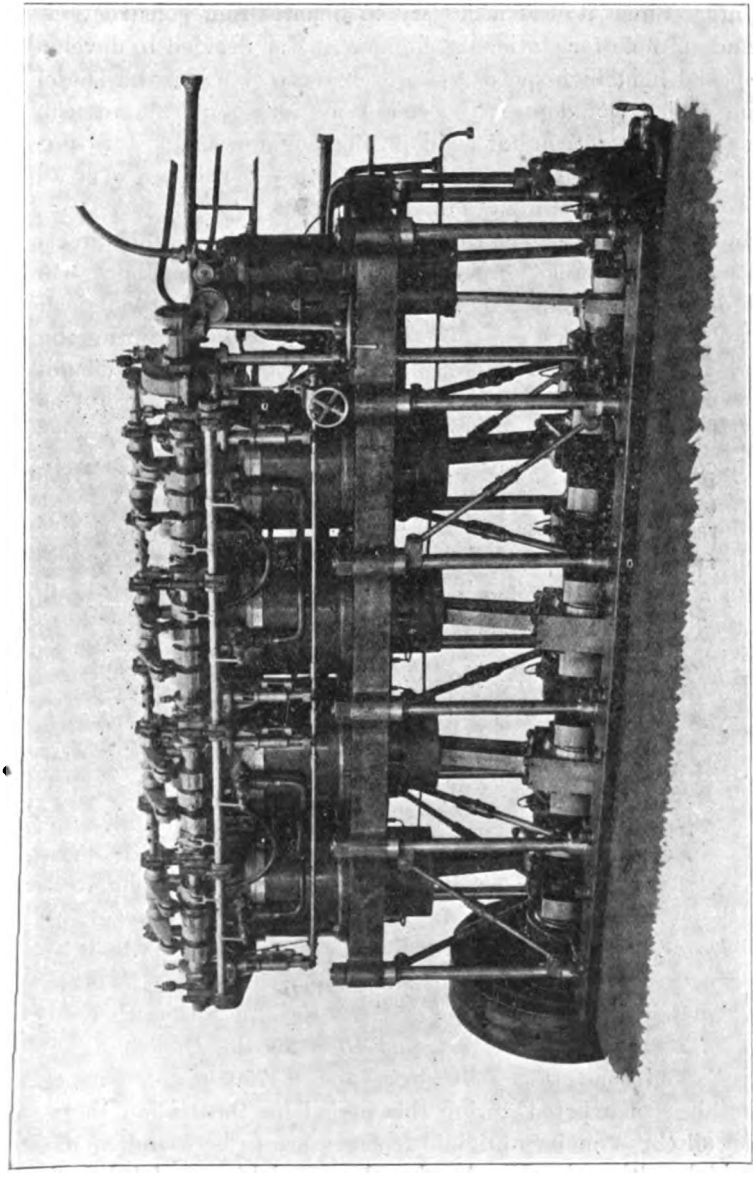

Fig. 2. Four-stroke Diesel Engine built in 1907.

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ments. Since it was necessary to depart from constructions found suitable for stationary engines, it was decided to develop a special light high-speed type of engine working on the Diesel cycle which would meet the conditions for submarine vessels. The principal reason for economising engine weight is to put every ounce saved into additional battery capacity, so as to increase the underwater radius.

For this purpose, in 1907, a light experimental direct-reversing four-stroke engine was built to develop about 350 b.h.p., Fig. 2. This engine closely resembles the American petrol-engines which were brought to this country during the war, and were so successfully used for patrol boats and submarine chasers. The results obtained from it were useful as a basis for the design of the two-stroke engine which was commenced in 1908. Two experimental engines were immediately built, Fig. 3, one of which had two cylinders and was of moderate speed, while the other was a four-cylinder model of high speed.

As a result of satisfactory tests, twelve engines were built in 1909 for six twin-screw submarines, each engine developing 300 b.h.p. at 500 r.p.m., Fig. 4. The German Government also ordered, in 1909, an engine of 850 b.h.p. at 450 r.p.m., Fig. 5. Its satisfactory performance induced the German Government to place an order for the propelling engines for submarine U.42. These were the only contracts for oil engines ever placed with a foreign firm by the German Admiralty.

Engines of the same type but of 300 b.h.p., and with slight alterations to the valve-driving gear, were built for a submarine for the Portuguese Navy, and these are still in service, giving satisfactory performance. Four similar engines, Fig. 6, built by Messrs. Scotts' Shipbuilding and Engineering Co., Greenock, were installed on British submarines S2 and S3. Others of 450 b.h.p. were built in 1912 and 1913 for the Danish Navy, Fig. 7, and some of a still larger power, 750 b.h.p., Fig. 8, were also constructed during this period for the Italian Navy.

On all these engines original features are to be found, many of which, although now abandoned, are of historical interest.

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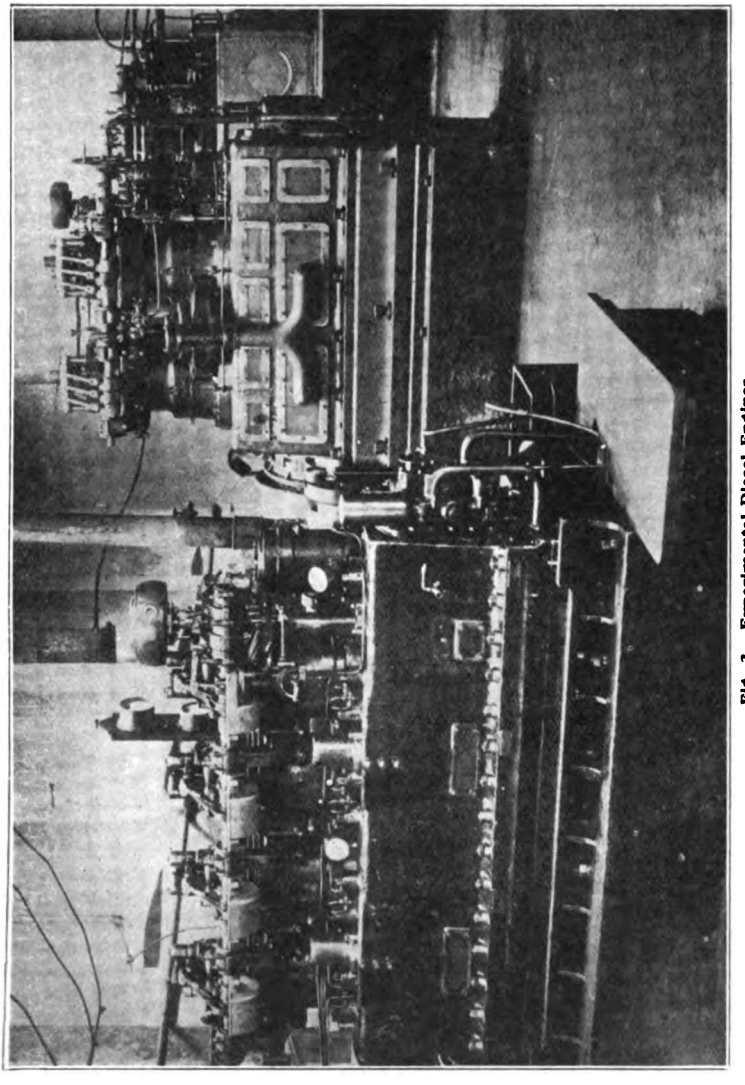

Fig. 3.—Experimental Diesel Engines.

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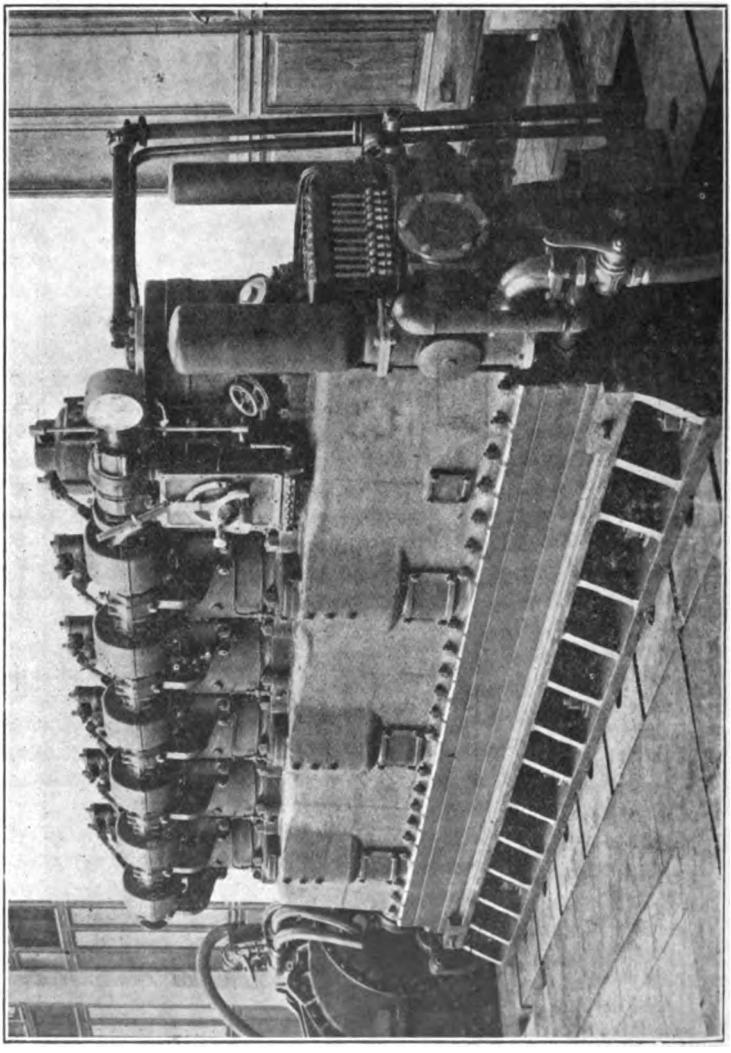

Fig. 4.—Diesel Engine for the "Medusa" type Submarines, 1909.

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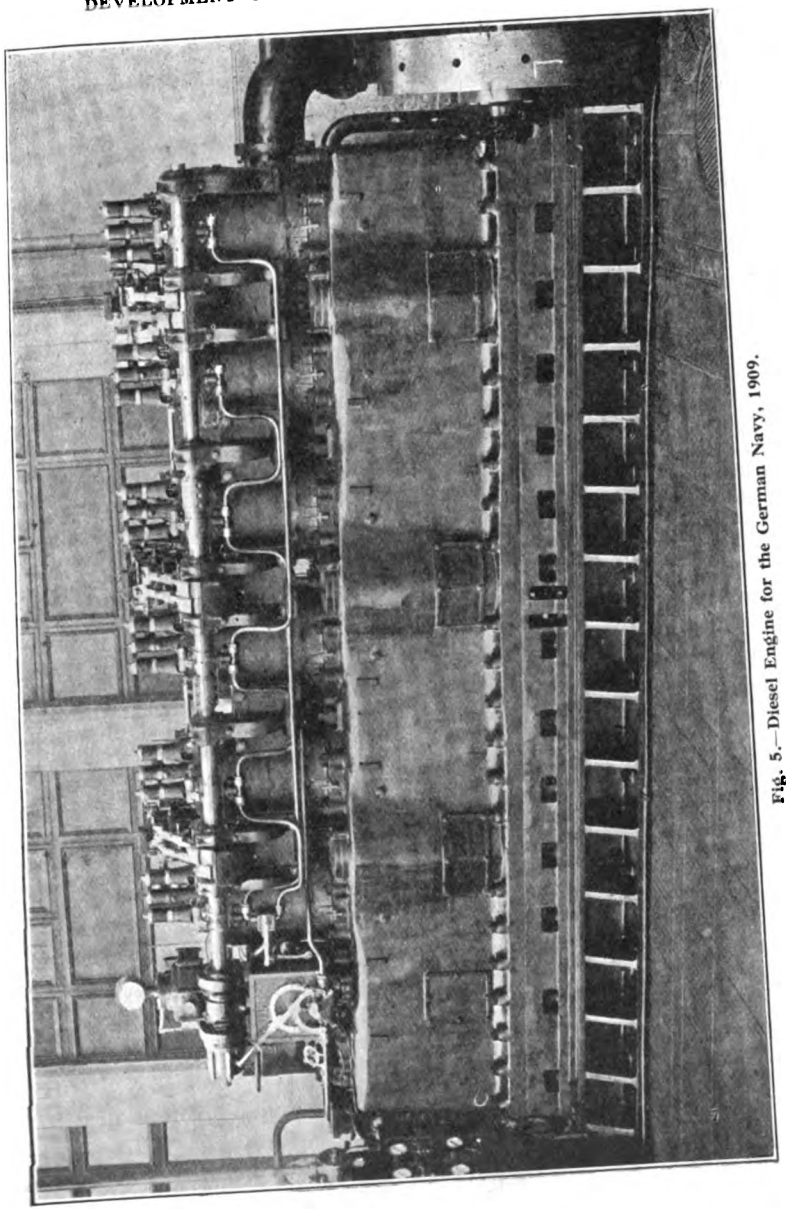

Fig. 5.—Diesel Engine for the German Navy, 1909.

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A characteristic feature, patented in 1909, was the arrangement of the cylinders in pairs, each main cylinder comprising a working and a scavenging-air cylinder with a stepped piston, the main cylinders of each pair being arranged with their cranks at an angle of 180 degrees to each other, and the entire distribution of the scavenging air being controlled by means of a single piston-valve arranged between the two main cylinders as indicated in Fig. 9.

The introduction of the scavenging air to the cylinders was effected by means of two valves in the cylinder head. The valves were operated by two shafts, driven from the crankshaft by helical gears and a vertical shaft. One of these shafts was placed near the cylinder heads and operated the valves, while the other was located inside the crank-chamber and drove the piston valves of the scavenging pump. The driving gear for the scavenging and fuel valves comprised a single eccentric and a system of rolling levers utilising the two opposite ends of the eccentric stroke for operating both fuel and scavenging valves, as shown in Figs. 10 and 11.

The engines were all fitted with reversing gear designed in 1910, and which is still employed in several cases, Fig. 12. The reversing was accomplished by the axial displacement of a section of the vertical shaft, and suitably proportioning the spiral gears in order to rotate the horizontal shafts to the correct angles. The rotation angle of the horizontal shafts was calculated for the necessary displacement of the eccentrics driving the scavenging valves and fuel valves. There were two starting-air cams, one for ahead and one for astern, which were moved horizontally by means of a shaft arranged inside the camshaft.

The Fiat Co. have always favoured the direct-reversing submarine engine, notwithstanding the fact that it is possible to manœuvre such vessels with their electric motors. It is better to have the Diesel propelling set entirely independent of the electric machinery, so that a breakdown of the latter will not interfere with surface navigation. During the war a submarine, which had its electric installation out of action owing

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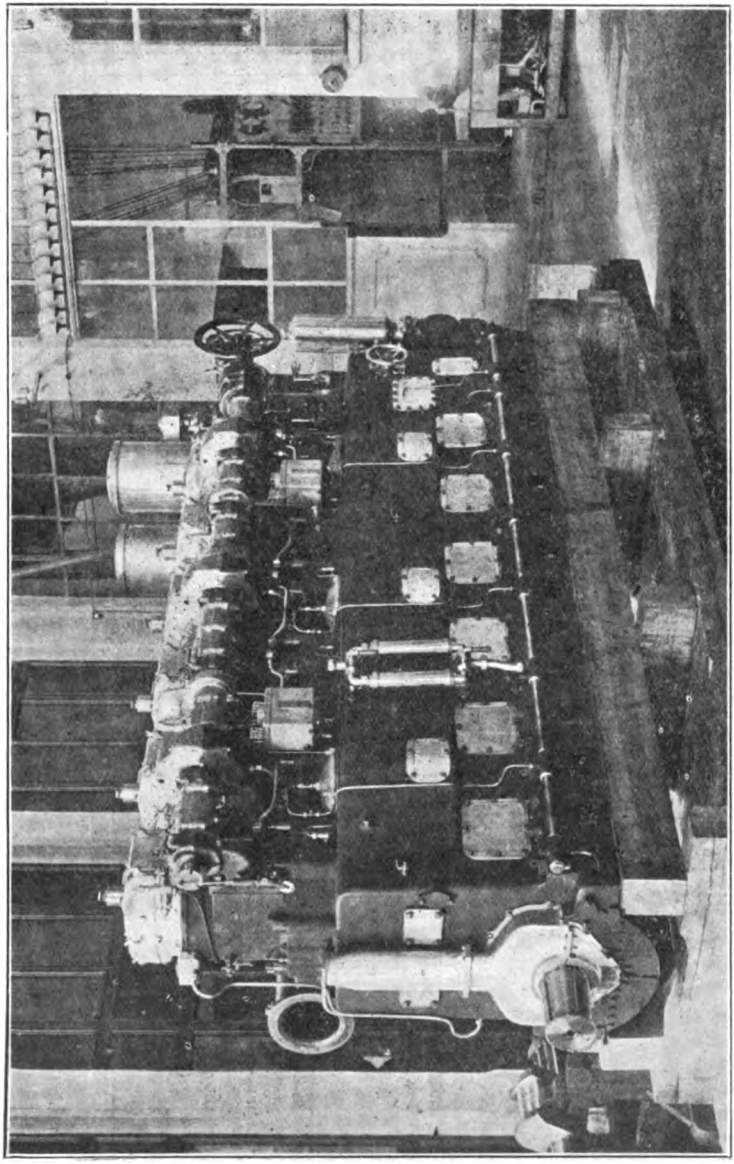

Fig. 6.—Diesel Engine for the British Navy.

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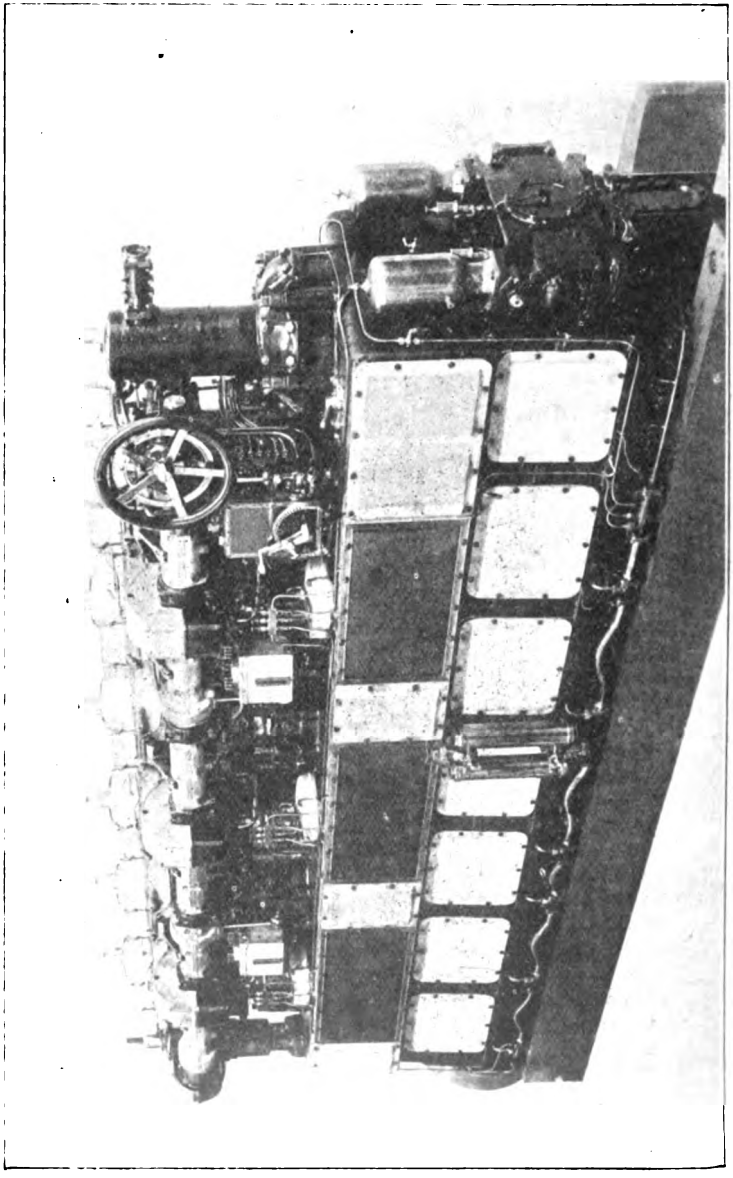

Fig. 7. Diesel Engine for the Danish Navy, 1912.

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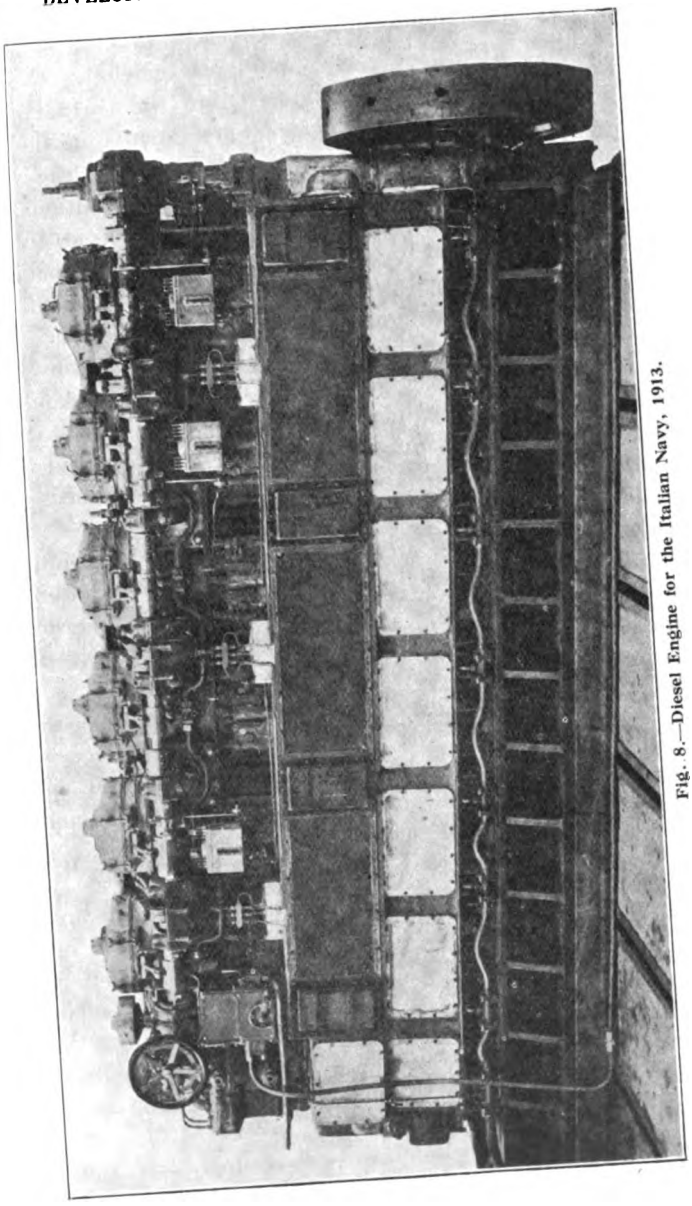

Fig. 8.—Diesel Engine for the Italian Navy, 1913.

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to complete flooding, was able to reach its base with the engines only, after having been rendered buoyant.

The running experiences obtained from the early types of engine have brought about many improvements in the later models. In the first instance, it was found that the valves in the cylinder head, although under easier conditions than those of a four-stroke engine, were not without disadvantages, as they were subjected to the high pressures and temperatures of the combustion chamber, and in addition, the small area involved a high scavenging-air pressure.

These drawbacks were eliminated by bringing the scavenging valves to the front lower part of the main cylinders and connecting them to the cylinders by means of specially-shaped passages and ports, of dimensions sufficient to keep the valves in communication with the cylinders for a period almost equal to that obtained by the valves in the cylinder head. This design simplified the cylinder cover, and removed the scavenging valves from the high pressures and temperatures. The scavenging ports are, of course, covered by the pistons during the combustion period and for most of the working stroke.

This construction, shown in Fig. 13, was successfully adopted for engines of 300 b.h.p. with four cylinders, which were built in 1912 for auxiliary sets, and later for main engines of 1,300 b.h.p. for the Italian submarines, type "Pacinotti," and for the previously mentioned German submarine U.42, Fig. 14.

A further improvement was obtained by altering the arrangement of the scavenging pumps. It was found that on the down stroke of the piston the partial vacuum formed in the scavenging-pump cylinder sucked oil from the crank-chamber, and the lubricating oil consumption was, therefore, rather unfavourable. There was also some direct leakage of scavenging air into the exhaust ports along the clearance between the piston and cylinder.

Sectional area in a submarine is extremely valuable, and the stepped piston, together with the space required for the

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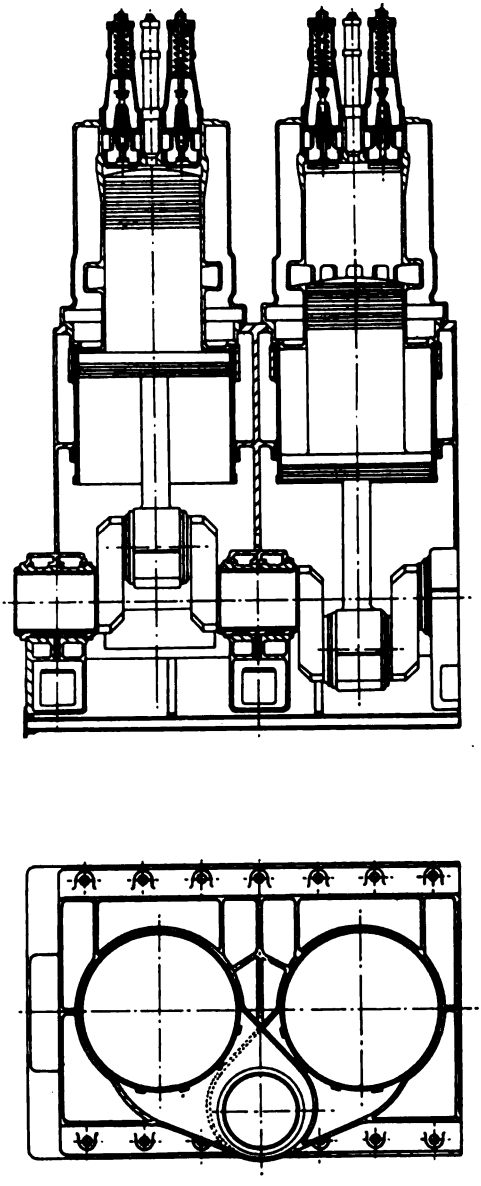

Fig. 9.

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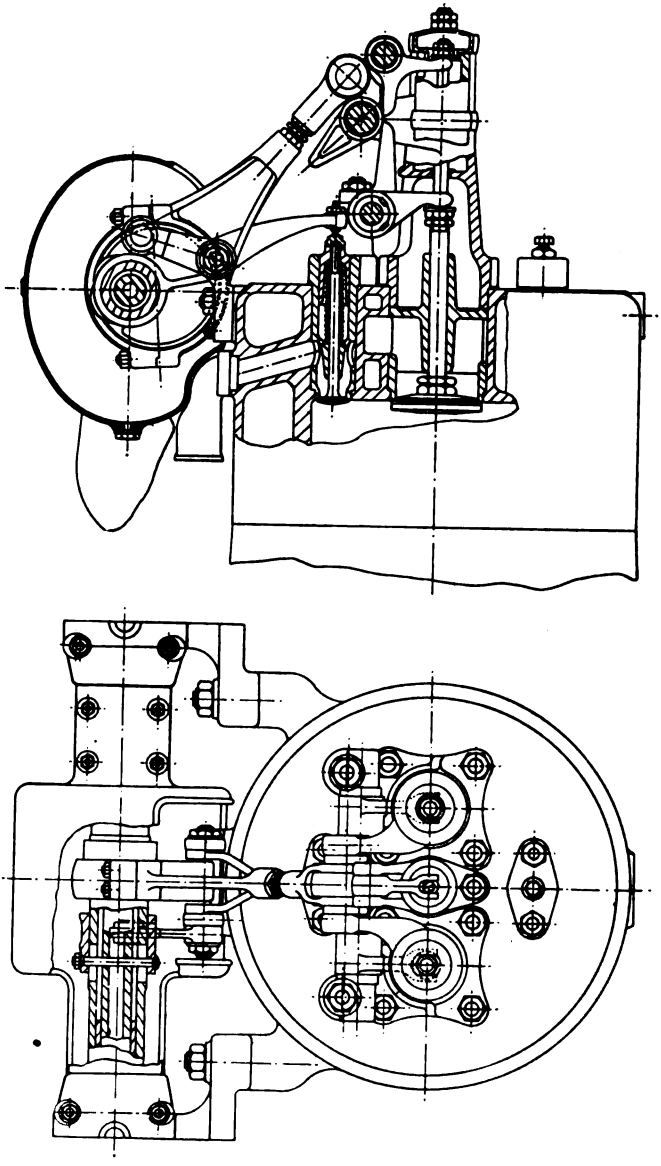

Fig. 10.

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valves, made the engines fairly broad, as well as increasing their height, so that there was not much room left for additional items, such as pipes, hydroplane and steering gear, and many details that run in a fore-and-aft direction in a submarine. An investigation was then made into the best method for reducing this area taken up by the engines, and in view of the considerations already mentioned, an engine of the trunk-piston type was developed, having the scavenging pumps driven by separate cranks. This construction is now standard on all Fiat engines, with certain necessary variations in design and position to suit the different types. From 1917 onwards submarine propelling-engines were fitted with crossheads, the advantages of this design being too obvious to need comment.

It is interesting to note that in the first engines provided with scavenging pumps separated from the main cylinders, the tandem arrangement of pumps driven by cranks at 90 degrees was adopted. The piston of the upper pump was driven by the central crank, and provided with a rod passing through the lower pump, while the piston of the lower pump was driven by two lateral cranks, Fig. 15. This arrangement has the advantage that it gives a silent suction and a more uniform discharge, but was abandoned in later constructions in favour of a simpler system.

As in this country, the war brought all developments in Italy to a standstill; attention had to be concentrated on the production of standard models, and many engines of 1,400 and 350 b.h.p. each were supplied to the Italian and allied navies.

Immediately after the war the construction of submarine engines was suspended, and as a wide experience had been obtained both during the pre-war and war periods, it was considered that as designed the engines would not completely satisfy the new requirements which submarines might be called upon to fulfil. Therefore, considerable attention was devoted to new investigations. An experimental engine, Fig. 16, was built in 1923, capable of developing the normal power of 400 b.h.p. per cylinder of 540 mm. diameter by 540 mm. stroke, at 325 r.p.m., and driving all its auxiliaries. It was

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subjected by the Italian naval authorities to a 12-days' run at full load. A maximum power of 450 b.h.p. per cylinder at

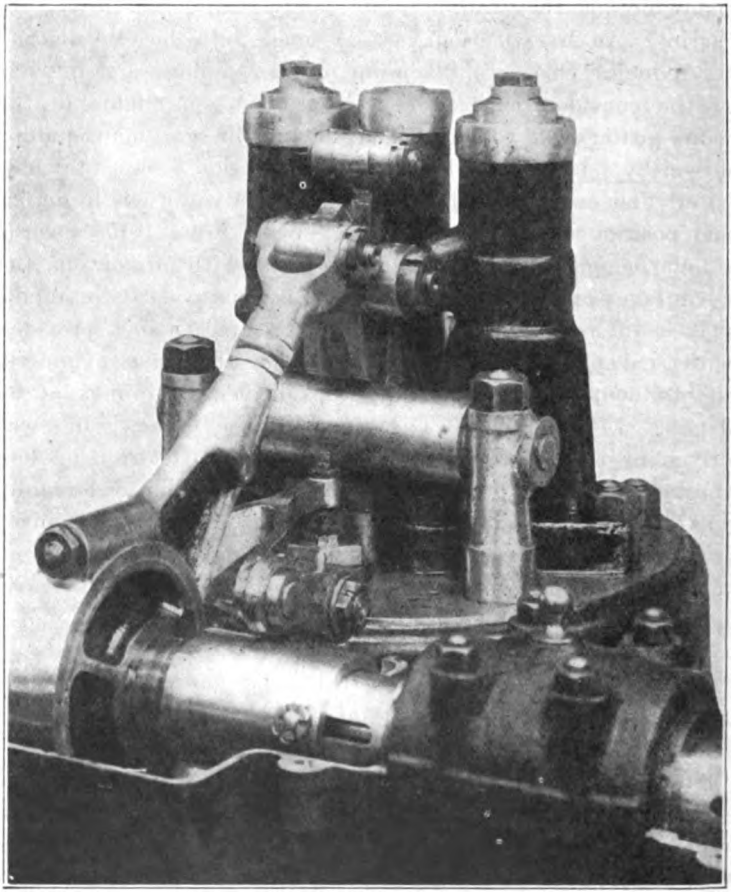

Fig. 11.—Valve-Driving Gear.

340 r.p.m. was obtained. The principal features were the extended use of cast-steel and extreme rigidity, the design being in many respects similar to that of a merchant-ship engine, in which accessibility is of great importance.

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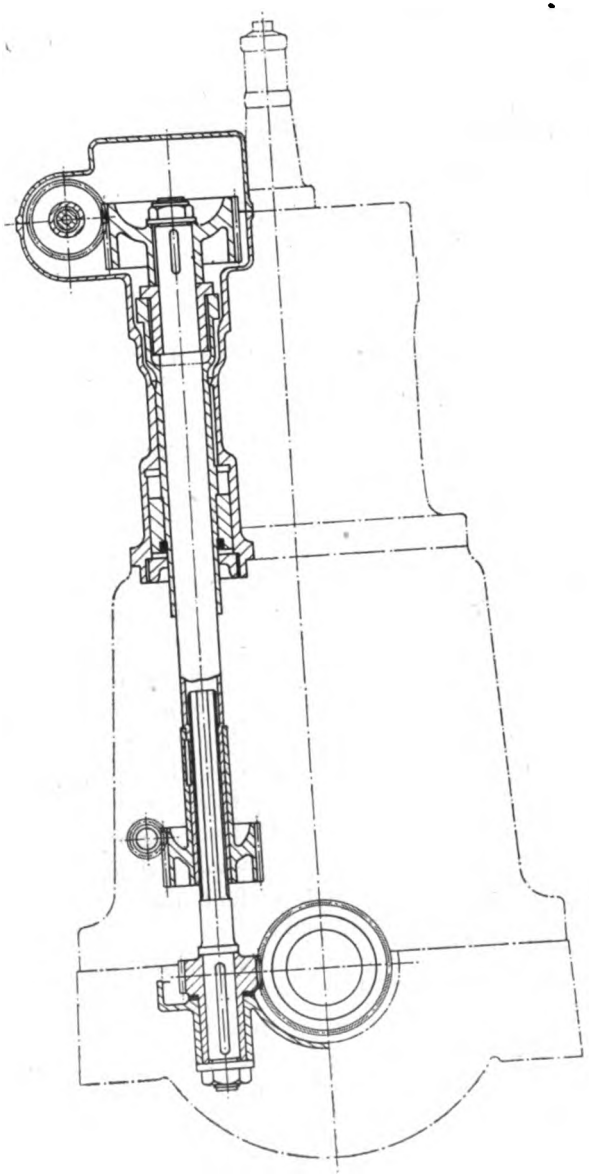

Fig. 12.

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This experimental engine proved the suitability of the two-stroke engine for high powers with low fuel-consumption, limited weights and sizes, and without the necessity of adopting high mean brake-pressures and piston speeds, as would have been required with a four-stroke engine of the same power.

As a set-off to this success, the builders of four-stroke engines, who cannot now maintain that the fuel consumption is better than in the two-stroke engine, have claimed that the four-stroke engine will last longer than the two-stroke engine, owing to the easier heat conditions. Their argument is based on a coefficient for the quantity of fuel burned in the cylinder in one hour referred to unit of area of piston, and they maintain that this coefficient, in ordinary cases, has a value of about ·23 lb. of fuel per hour per square inch of piston surface for four-stroke engines, and about ·34 lb. per square inch per hour for two-stroke engines.

Apparently, therefore, the thermal stresses are greater in two-stroke engines than in four-stroke engines, but a superficial examination of the question will show that such figures are practically meaningless. While a coefficient of this kind may be assumed as a basis for comparing the intensity of combustion in boiler furnaces, or in other apparatus in which the combustion is continuous, it has little value in the case of the oil engine. It is, in fact, based on the misunderstanding arising from referring the total quantity of fuel burned to the time instead of to each cycle.

If the fuel introduced into the cylinder during each cycle were uniformly distributed for the whole duration of a revolution of the two-stroke engine and two revolutions of the four-stroke engine, instead of being injected and burned during a period of time which corresponds to a small fraction of a revolution that is almost identical in the two types of engine, a true comparative coefficient would be obtained, and what in ballistics is known as "density of charge"; which means the quantity of fuel introduced to the cylinder for each combustion referred either to the cylinder capacity or to the piston surface. This system of comparison gives ·37 lb. of fuel per cycle per

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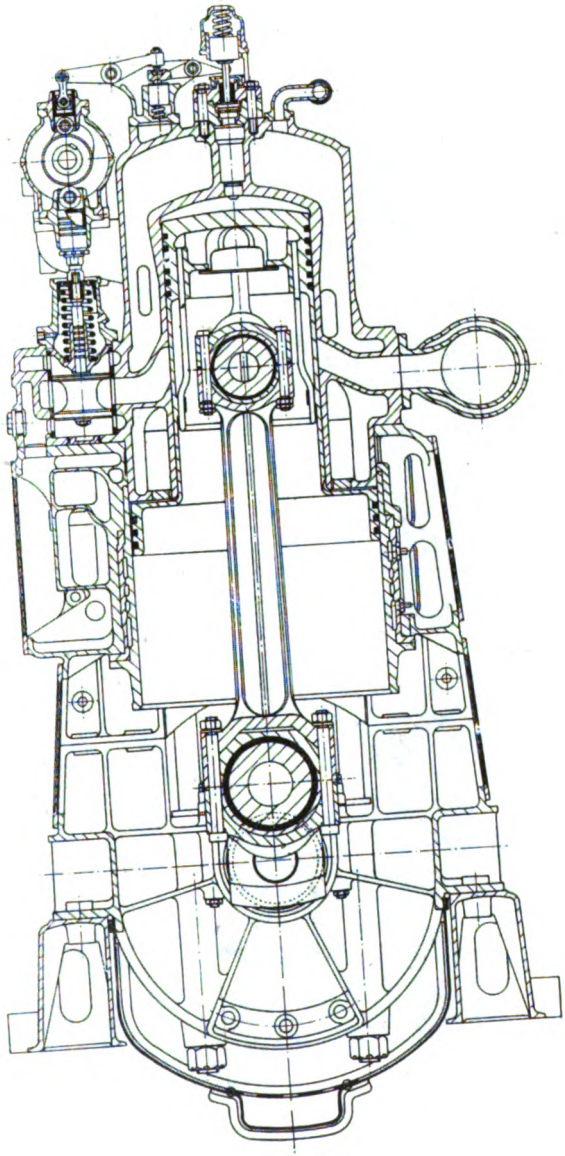

Fig. 13.

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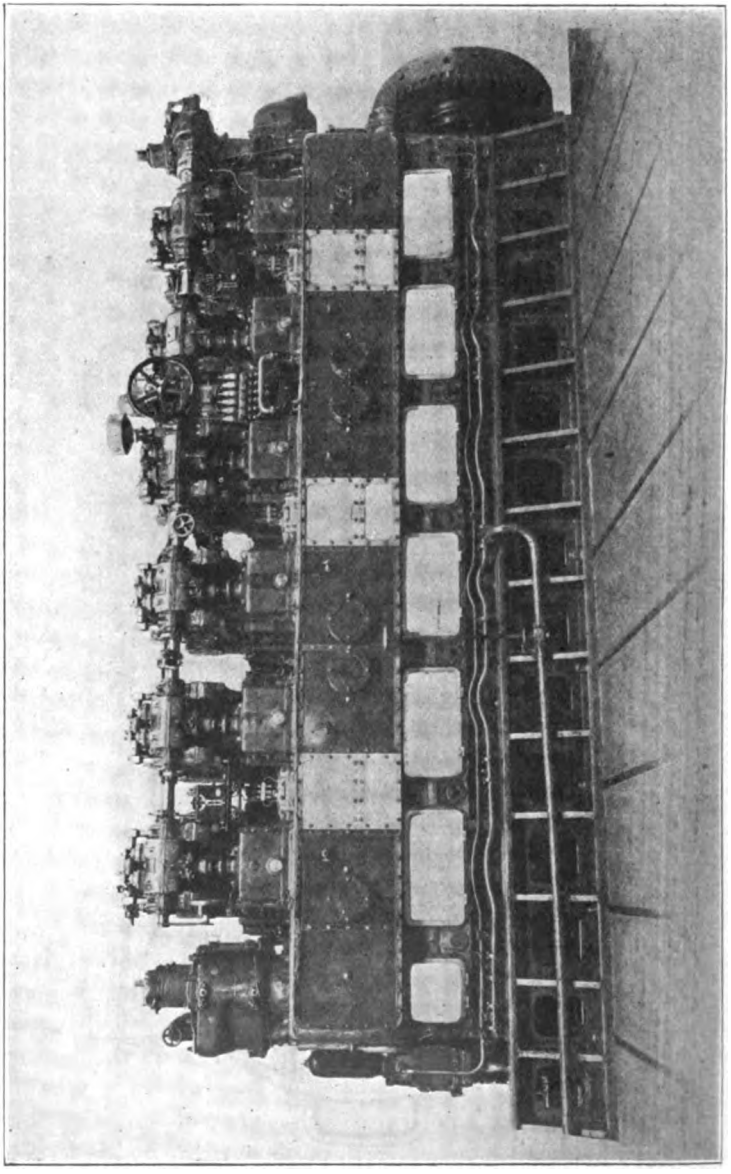

Fig. 14. - Diesel Engine for the German Navy.

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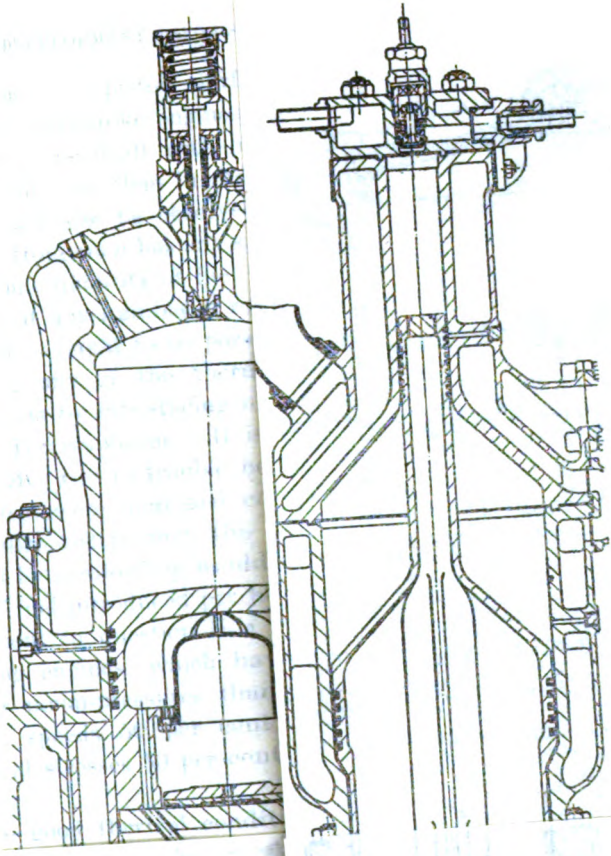

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square inch of piston surface for two-stroke engines and ·5 lb. for four-stroke engines, from which it will be seen that the heat to be dealt with by the two-stroke engine is about 25 per cent. less than in the case of the four-stroke engine.

It should also be observed that if the coefficient proposed by four-stroke men has any significance, it would be immaterial if the same quantity of fuel per hour were burned in the same cylinder at any number of revolutions. If the above argument is sound, it ought to be possible to operate an engine, without changing any of the thermal stresses, at half the normal revolutions by introducing into the cylinder twice the amount of fuel per revolution. It is easy to see that such conditions would give rise to trouble because, if the quantity of fuel per revolution were increased continuously by, say, 20 per cent. more than the normal, the usual phenomenon of overheating caused by overloading would become visible, even if the quantity of fuel introduced per hour were less than normal. If the coefficient in question is a criterion, it is obvious that fast-running engines, which have, in most cases, equal or even higher mean-pressures than slow-speed engines, but run at piston speeds 50 per cent. higher, would be subjected to thermal stresses 50 per cent. greater, and this is far from the truth.

The good thermal conditions of the two-stroke engine are also proved by the heat transmitted to the water, which is very moderate, and less than in the case of the four-stroke engine. In the two-stroke type the time that the walls are exposed to the flame is approximately one-third of the working cycle, whereas in the four-stroke type it is about one-half of the working cycle. It should also be observed that the walls of two-stroke engines are cooled by the scavenging-air current immediately after combustion. As a rule, the quantity of air is in excess of that required, and appreciably assists the cooling.

The results obtained with this engine induced the Fiat Co. to construct a new series of high-powered engines, Fig. 17, giving from 2,000 to 2,200 b.h.p. at 380 r.p.m. in eight cylinders. Ten of these engines have been completed

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for the Italian and Brazilian Navies, and the first two have made non-stop runs of 12 days' duration, including tests at 10 per cent. overload, which were the conditions

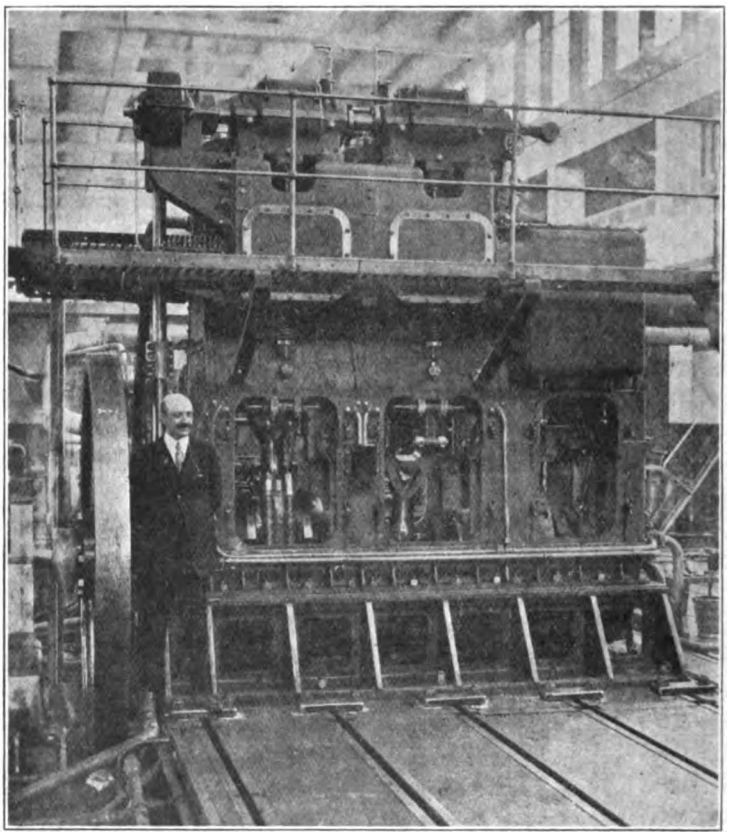

Fig. 16.—Experimental Two-Cylinder Diesel Engine, 1923.

of the contract. It was also stipulated that the time allowed for forced stops should not exceed 15 minutes. So far as is known, no other navy has specified such severe official tests. At the end of one of these trials, an inspection of the dismantled parts showed that all the pistons were clean, and no

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rings were broken, damaged, or chipped at the ends of the angle joints. The fuel consumption recorded was 195 grammes,

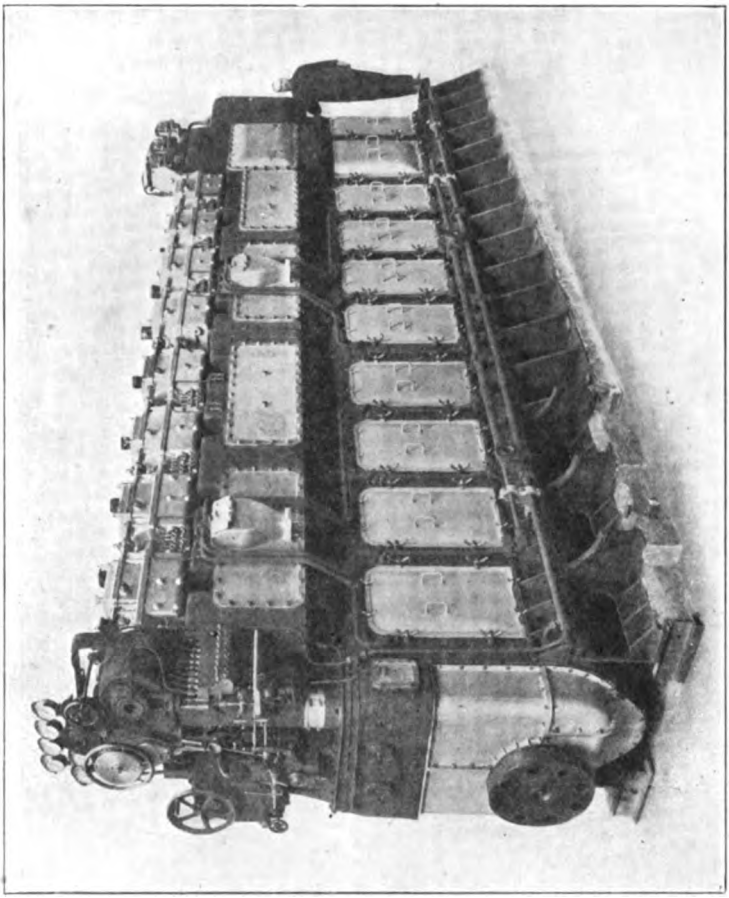

Fig. 17. High-Powered Diesel Engine.

or ·435 lb. per b.h.p. per hour, which is satisfactory for a high revolution two-stroke submarine engine having a piston speed of 1,140 feet per minute and driving its own scavenging pump and compressor.

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Non-experimental engines of this design, capable of developing from 3,200 to 3,600 b.h.p. in eight cylinders, could be

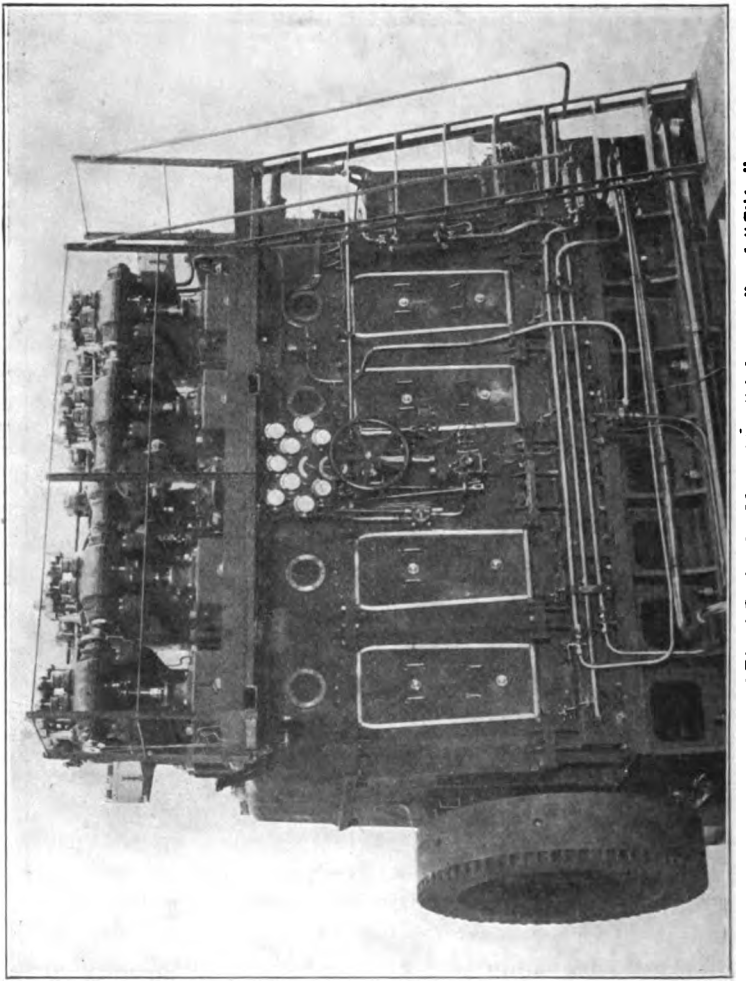

Fig. 18.—Type of Diesel Engine for Motorships "Acheronte" and "Stige."

installed in yachts, cross-channel vessels, or other high-speed craft.

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The development of engines for surface ships has been as important and historical as in the case of submarines. Between

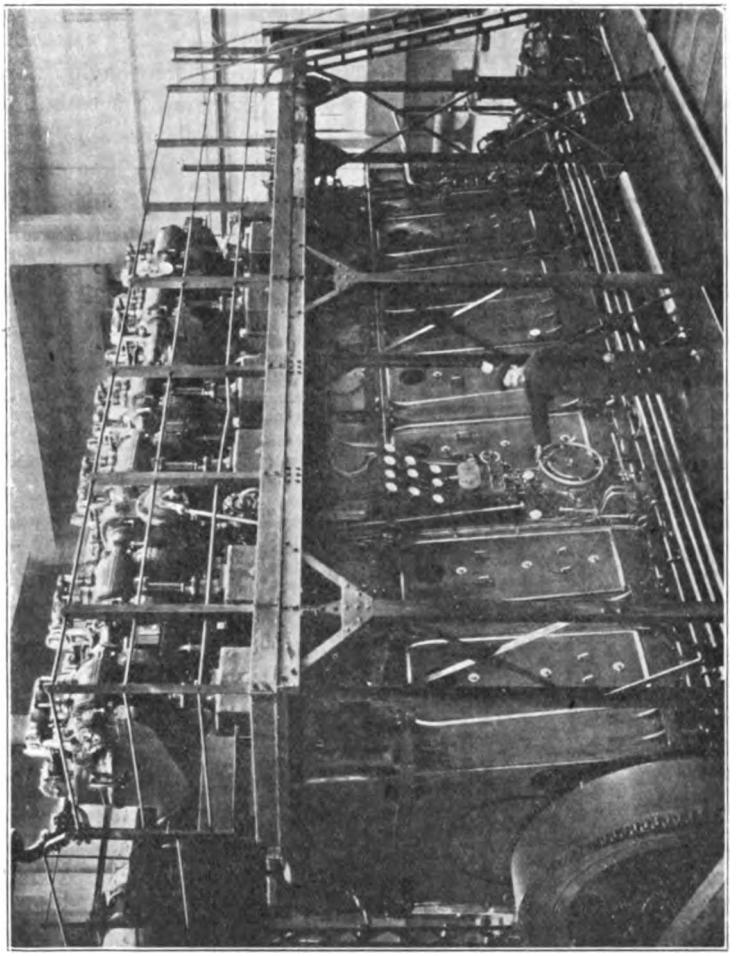

Fig. 19. - Diesel Engine for Motorship "Ceara."

1910 and 1913 many engines were installed in various types of small craft with satisfactory results. In 1913 two engines, each having four cylinders of 390 mm. diameter by

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550 mm. stroke, and developing 550 b.h.p. at 210 r.p.m., were built and installed in the motorships "Stige" and "Acheronte." These vessels have since been acquired by private shipowners, and are still giving good service. Fig. 18 shows this early design of engine.

In 1915 two engines of 2,300 b.h.p., each having six cylinders and developing their power at 125 r.p.m., were built, and this formed an important milestone in the development of the Fiat engine. They were fitted in the Brazilian depot ship "Ceara." Fig. 19 illustrates one of these engines, the internal construction of which is shown by the cross-section, Fig. 20, and by the longitudinal-section, Fig. 21.

The admission of the scavenging air takes place through ports, which are controlled by cam-operated valves fitted in the front lower part of the cylinders. The scavenging ports are longer than the exhaust ports, in order to get the same period of scavenging as was given by valves in the cylinder head. Later on, however, two experiments were made on the same engine, one with a liner having scavenging ports longer than the exhaust ones, and the other with the air ports exactly the same length as the exhaust ports. The results of these tests showed that there was no advantage in having longer scavenging ports, chiefly on account of the loss in efficiency due to the increased port length counterbalancing the effect of any slight additional air that might be got into the cylinder. It was, therefore, decided to dispense with the practice in all future engines either of the high- or slow-speed types, and to make the air ports exactly the same length as the exhaust ports. Such an arrangement gave easier conditions for the scavenging valves, since the pressures and temperatures to which they are exposed are reduced. In addition, an improvement in the efficiency of the engine resulted.

It will also be observed that the pistons for this engine come into the crank-chamber, a construction which is still carried out by some firms to-day. This arrangement was abandoned very early in the development of the Fiat engine, and the

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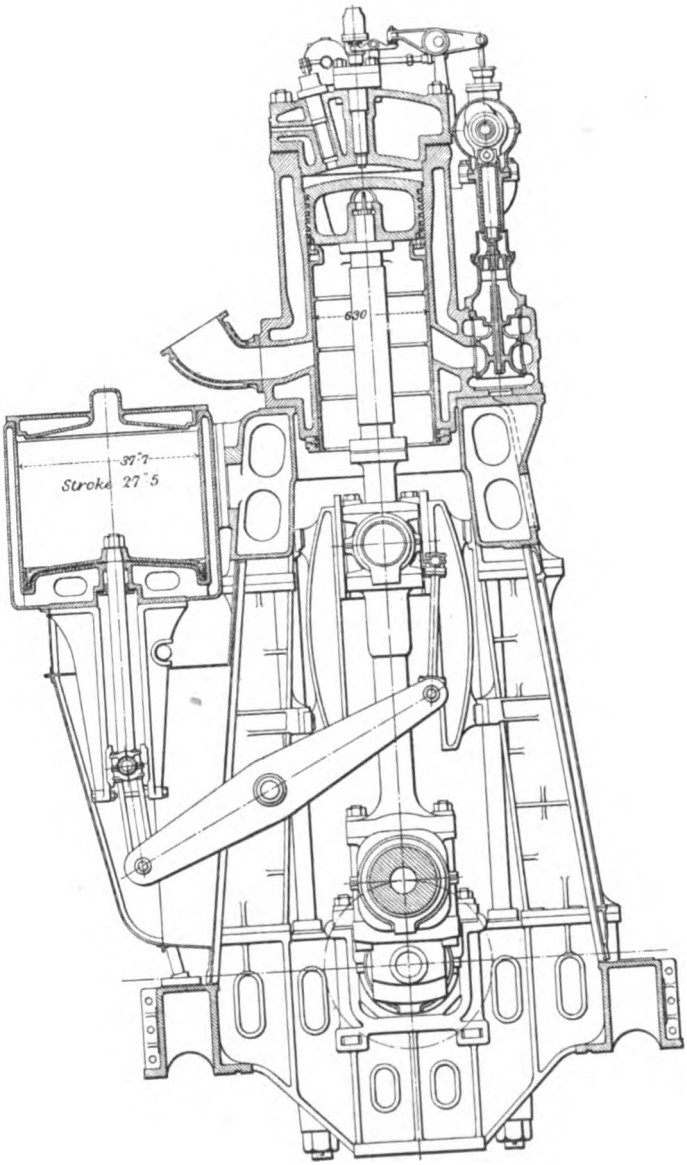

Fig. 20.

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cylinders were entirely separated from the crank-chamber by a diaphragm. The advantages of such a construction will be referred to when the latest type is described. On test the engines of the "Ceara" gave a fuel consumption of 195 grammes, or ·433 lb. per b.h.p. per hour, which was the lowest fuel consumption then recorded for any two-stroke marine oil-engine. The "Ceara" was at that time the most powerful motor vessel afloat, so it will be seen that in this vessel the earliest experience of the now popular two-stroke engine of large size was obtained.

In "Engineering" for 25th February, 1916, a table was published giving particulars of high-powered marine Diesel engines, showing that the "Ceara's" machinery developed 384 b.h.p. per cylinder, whereas the largest four-stroke engine developed only 270 b.h.p. per cylinder. A study of the principal features of these early engines will show that they very nearly correspond to what is to-day considered the last word in oil-engine design.

With the termination of the war it was possible to devote more time to the development of the merchant type of engine, and four-cylinder engines were constructed developing 1,250 b.h.p. at 110 r.p.m., and six sets of exactly similar design were fitted into the three cargo ships "Ansaldo San Giorgia" I, II, and III, between the years 1919 and 1921. Up to date these three vessels have each covered about 320,000 miles, representing approximately 32,000 hours of running. As showing the reliability attained by the marine oil-engine, it might be stated that the "Ansaldo San Giorgia II" passed through a gale which smashed the skylights, carried away the steering gear, and generally made the ship a wreck as far as the deck gear was concerned. It was necessary to run one engine astern and one ahead for a period of about 30 hours, and it was only the reliable working of the machinery, despite the fact that the engine room was flooded, that prevented the ship from becoming a total loss. The first of these three vessels recently made a non-stop run of 45 days, which is one of the longest on record.

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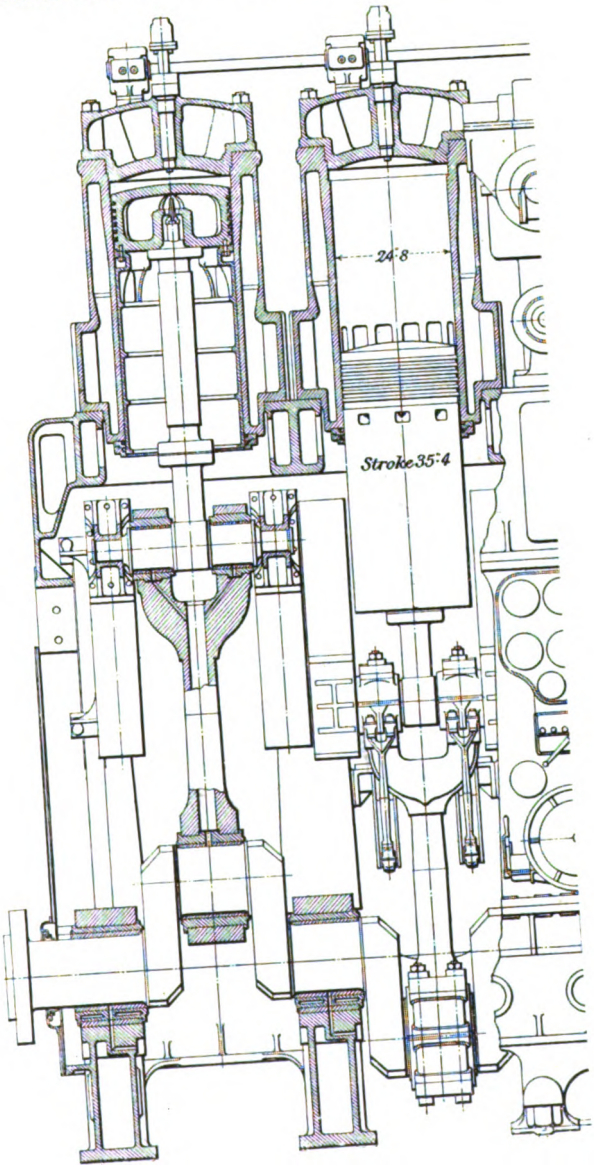

Fig. 21.

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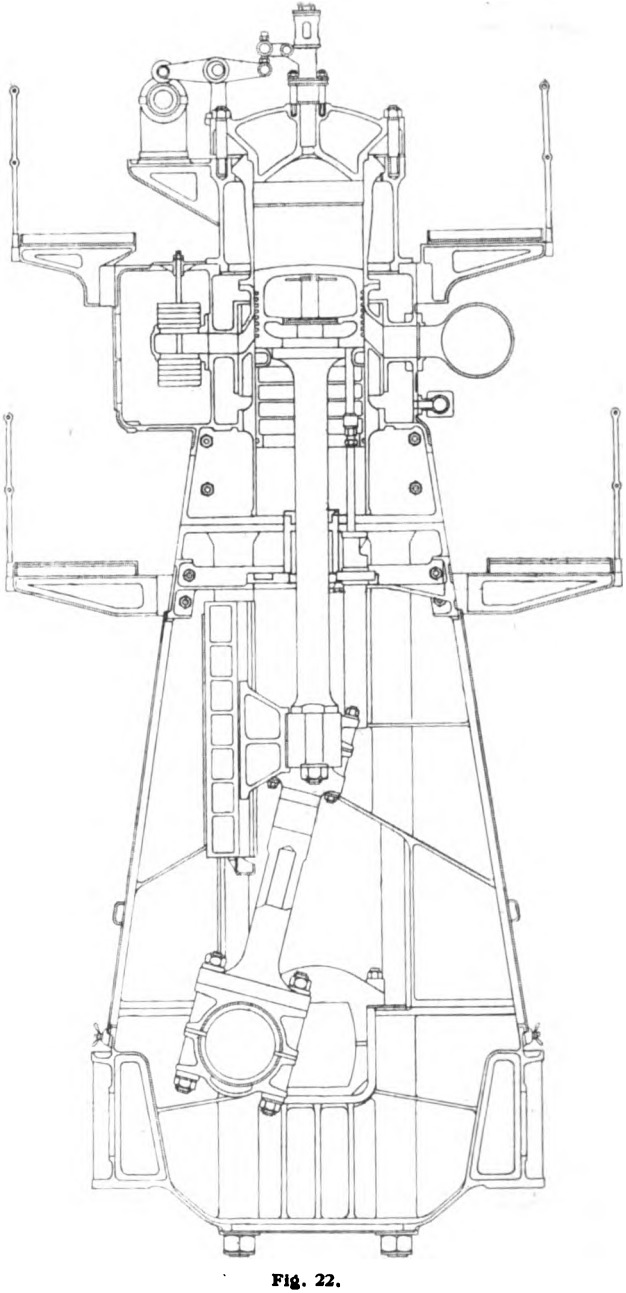

Fig. 22.

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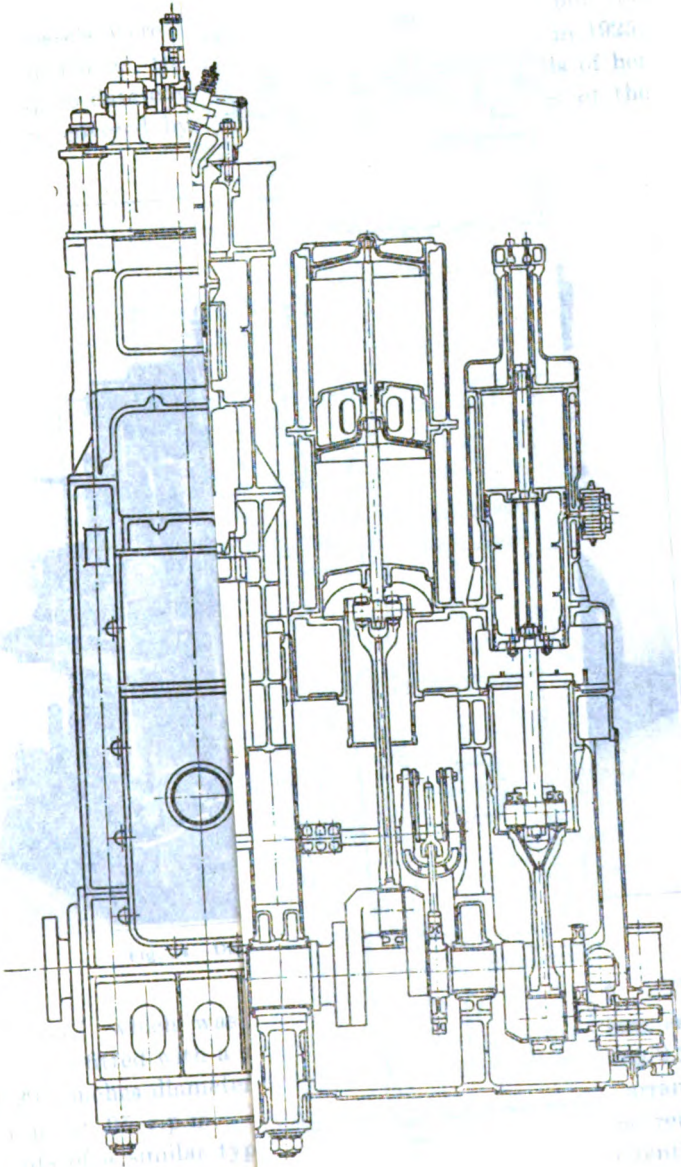

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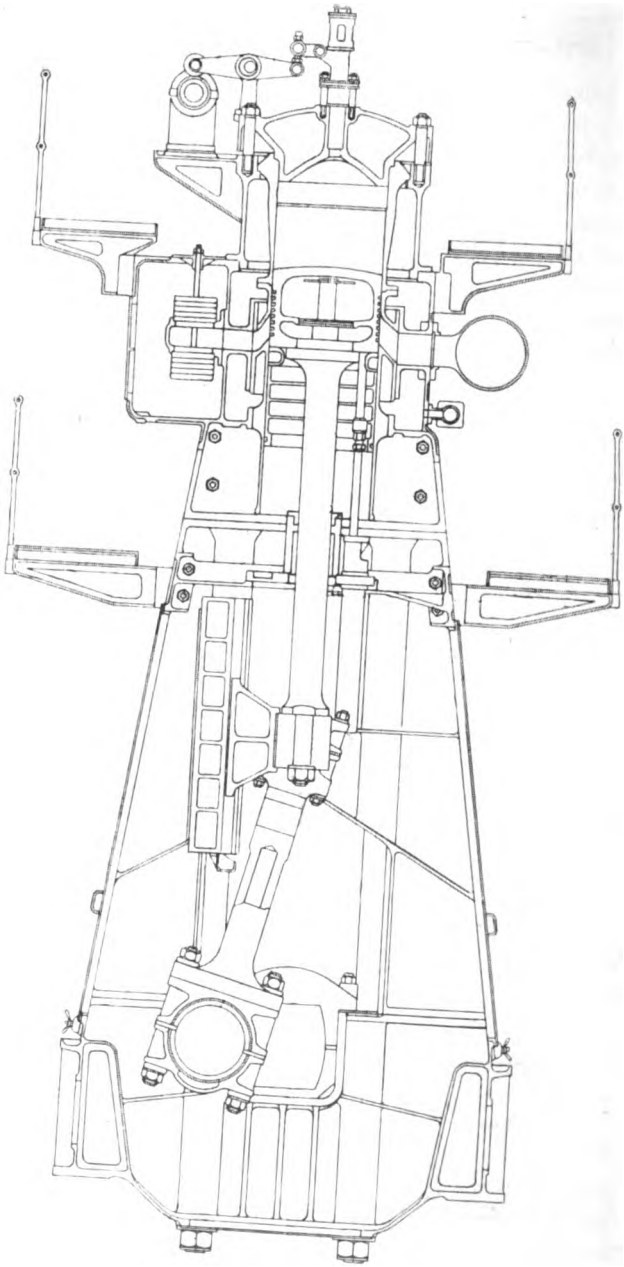

Fig. 22.

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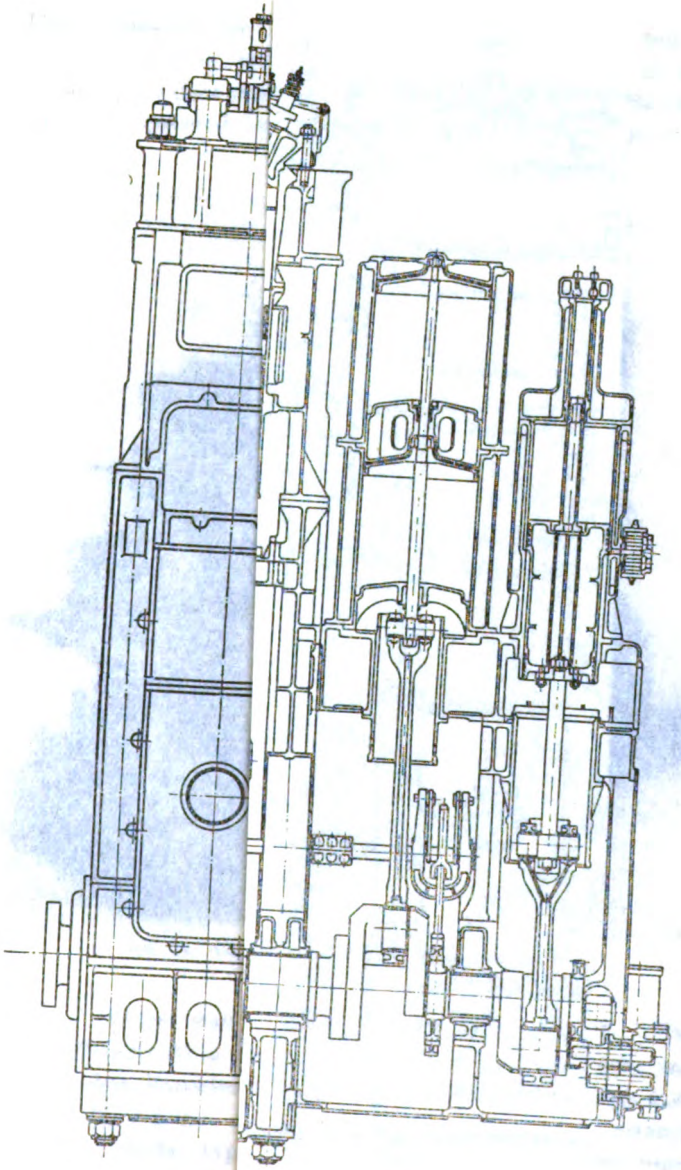

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These vessels were followed by numerous others, but the next of importance, the "Mauly," was commissioned in 1925, and has up to date covered 100,000 miles. The details of her engines are covered by the description of the engines of the

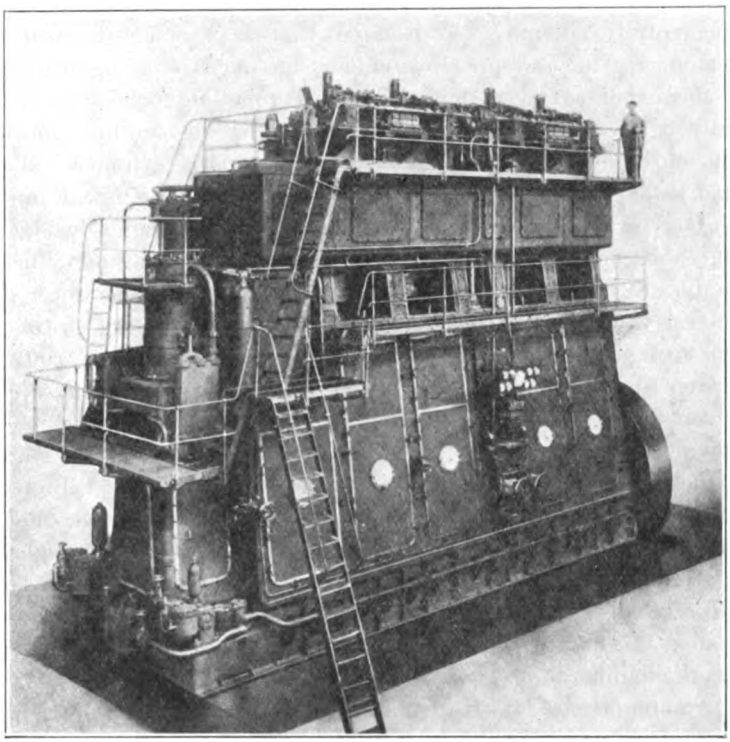

Fig. 24.—Diesel Engine for Motorship "Maria."

"Maria," which was put into service late in 1926. This vessel is fitted with a single engine having four cylinders, each of 29·5 inches diameter by 49·2 inches stroke, developing 2,200 b.h.p. at 95 r.p.m. Figs. 22 and 23 are sectional arrangements of a similar type, and Fig. 24 is a photographic reproduction which will enable the design to be studied. Attention,

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however, may be drawn to some of the outstanding features of this engine.

In the first place, the cylinders are entirely separated from the crank-chamber by a diaphragm plate, the piston rods passing through light stuffing-boxes into the crank-chamber. This arrangement necessitates the use of crossheads, and, incidentally, it may be observed that a reversion to trunk pistons recently adopted by builders of four-stroke engines, as a means of saving weight for main propelling purposes, can only be looked upon as a retrograde step, since it introduces the old controversy of carbonised oil from the cylinder walls and leakage from the piston-cooling gear finding their way into the forced lubrication system in the crank-chamber. Considering the present state of our knowledge of ring and liner material, the increased liner wear due to the connecting-rod lateral thrust is another serious matter. In support of this, one firm who build two-stroke crosshead and four-stroke trunk-piston engines have reported that the wear of the former is about half of that experienced with the latter, on engines having cylinders about 14 inches diameter. With the construction now adopted no carbonised oil from the cylinder walls or incidental leakage of water from the piston-cooling gear can find access to the lubricating oil in the crank-chamber, so that a prolific source of trouble in early engines has been eliminated. As will be seen from Fig. 22, no water joints or glands in connection with the telescopic tubes are inside the crank-chamber.

An important detail is that the lower scraper rings for the piston are arranged in the piston itself. In some designs of engine these are of the inward-springing type, and are attached to the bottom ends of the liners. To facilitate the removal of the piston it is, as a rule, better to dismantle these rings. This construction has two defects. In the first place, the clearance between the piston skirt and liner is converted into an annular pumping cylinder, which may cause lubricating oil to be drawn in from the crank-chamber on the upward stroke of the piston, Fig. 25. Secondly, both liner and piston

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skirts must be lubricated, giving an increased lubricated area. As no special gear is fitted to lubricate the piston skirts, they must depend on chance, which cannot be considered the best practice.

By combining them in the piston, as already stated, the whole piston can be withdrawn with all the necessary rings in place, which minimises the time for overhauling. With this

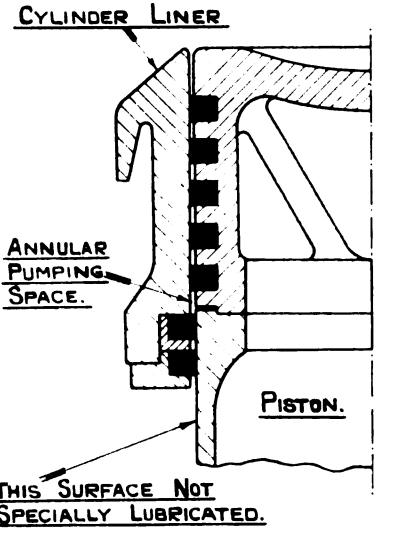

Fig. 25.

system, the number of types of piston rings to be made and carried as spares is reduced. Undoubtedly the construction adds a little to the height of the engine, but it is very simple and extremely convenient.

All bearing surfaces are large, and copiously lubricated with oil at a pressure of about 20 lbs. per square inch. The cross-head bearings are fed from the same system, and so far no overheating has been experienced. A special high-pressure system for lubricating the gudgeon pins, involving additional telescopic gear and special pump, is, therefore, not required.

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The crossheads are of the open-fronted marine type, which is simpler than the double type shown by the sectional drawing of the engines for the "Ceara." This means that there is a large uninterrupted space in front of the crossheads for overhauling. They are also cheaper to manufacture, and so far no trouble from the smaller slipper area for astern running has been experienced.

Piston heads and cylinder covers are of cast-steel instead of cast-iron, so that they can be made thinner to facilitate the more active transfer of heat, and give a smaller heat-drop between the external and internal surfaces. There are no large inlet and exhaust valves, so that the cover can be of a simple and well-cooled design. There are only three small tubes connecting the interior and exterior walls for the valves, and the cooling of this part is extremely good, since there are no heavy sections of metal anywhere.

The design of the upper portion of the liner and piston crown has always been a subject of serious discussion. Undoubtedly these are the parts in any oil engine that have been a fruitful source of trouble, and they formed the subject of very careful investigations before the present design was adopted. All liners must have a thick flange, which in most designs interferes with cooling and gives high stresses. In addition, the temperature of the inner surface of the liner is higher at this point, and the lubricating oil is subjected to conditions which are conducive to carbonisation. This is overcome in this design by dropping the cylinder cover inside the liner for a short distance, so that the combustion gases are kept away from the thick flange. Fig. 26 shows a comparison of these pressure- and heat-resisting walls for (a) the Fiat engine; (b) a normal two-stroke engine; and (c) a normal four-stroke engine. With respect to the piston, the combustion surface of the crown is of convex form, which is the best shape for resisting pressure stresses, and has given excellent performances in practice. In concave pistons there is always an undesirable volume of metal where the crown meets the cylindrical portion, due to the necessity of having a large

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internal fillet. In some engines the first ring is arranged fairly close to the crown and in this thick metal part, so that it is away from the cooling medium, so much so that better results are obtained by omitting it altogether. The first ring is placed well down the piston, so that the combustion gases are thoroughly cooled before reaching it.

The shape of the piston crown is also better for scavenging, since it helps to deflect the scavenging air slightly in an upward direction. That the scavenging of these engines is good is supported by the fact that, although the normal rating of this engine is 2,200 b.h.p., at revolutions increased according to the propeller law, the normal overload test is about 2,900 b.h.p. for 42 hours, which has been accomplished on several of these motors. The ordinary practice is to give each engine a test of this duration at the absolute maximum overload that can be carried, in preference to a long test at the normal power.

Since the air ports are of the same length as the exhaust ports, it is necessary, as already stated, to fit a non-return valve in the scavenging belt. In some constructions this valve is of the piston type, and positively operated from the camshaft. After careful experiments, it was found unnecessary to have this complication, and simple multiple-plate automatic valves were substituted with equally satisfactory results. This is now the standard practice on practically all engines.

The design of the scavenging pump and compressor follows along normal lines, and there is not much to choose between engines of different makes in these respects, excepting that in the case of the Fiat engine the principle of entirely separating the air cylinders from the crank-chamber by means of diaphragms and piston rods is again rigidly adhered to. This involves the use of crossheads similar to what are considered necessary for the working cylinder. While this means additional cost, it prevents elliptic wearing of the cylinders by the connecting-rod side thrust, and economises lubricating oil. It also prevents crank-chamber lubricating oil finding access to the air cylinders.

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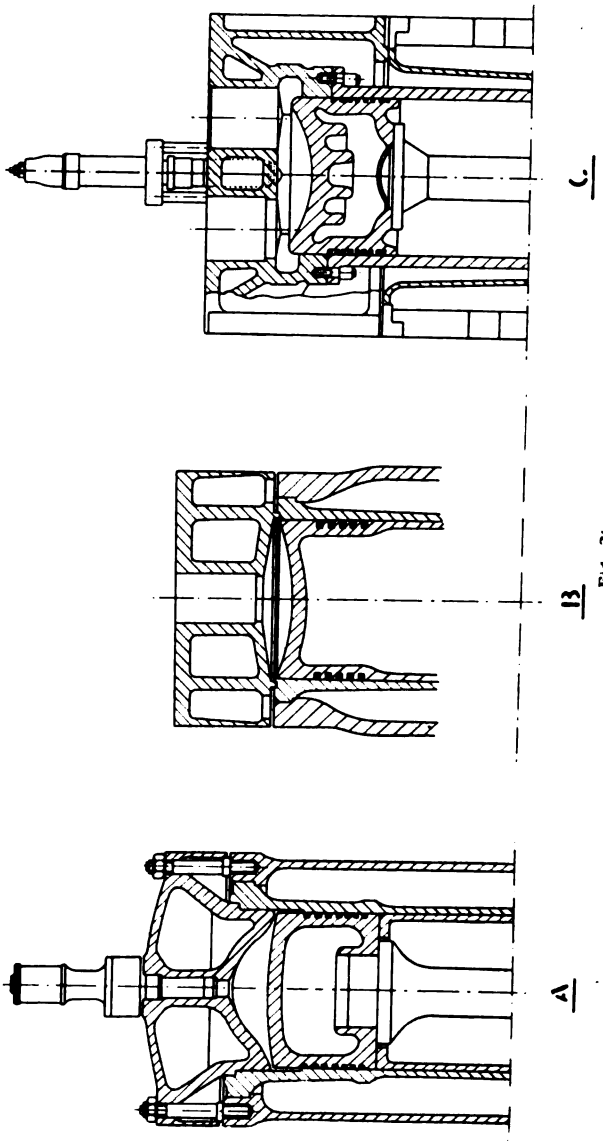

Fig. 26

The system of reversing is the well-known one in which double cams are provided. The operating levers are first lifted clear of the cams by means of eccentric fulcrum-pins, after which the camshaft is moved to the required position

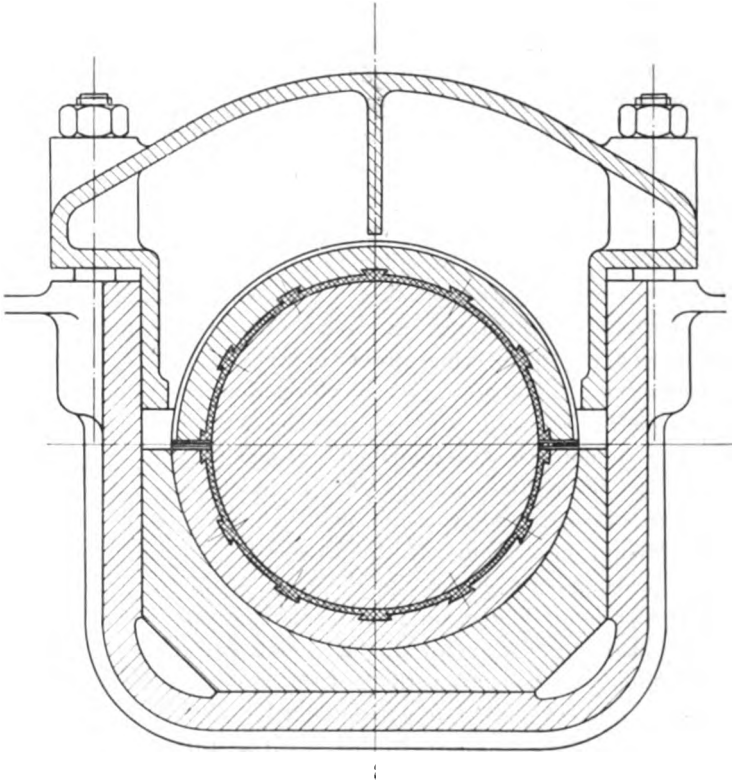

Fig. 27.

in a fore-and-aft direction, either by hand or by a servo-motor. The engine is provided with the usual arrangements for controlling the speed and the output from the injection-air compressor, and the manœuvring gear is fitted with the usual interlocks for preventing faulty operation. An overspeed

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governor is incorporated with the pump gear, and is of a simple throw-out type.

It is now generally agreed that the alpha and omega of the design of Diesel-engine framing is rigidity. Flexibility in a fore-and-aft direction gives rise to undesirable vibrations, even in engines that are supposed to have good primary and secondary balance. A study of Figs. 23 and 24 will show that the framing is designed as a rigid rectangular beam, the depth being from the cylinder covers to the oil sump. Although it is cast in sections, it is strongly bolted together, giving an extremely rigid structure. This design is possible with two-stroke engines on account of their short length, but it is a most desirable feature to have in any main propelling-engine for marine purposes. In order to relieve the framing of the direct loads due to the working piston, long through bolts are fitted which extend from the face on which the cylinder covers are placed, to the bearing girders of the main bedplate. This construction will always give good results, providing that all bolts are tightened up to the same degree, which in the case of these engines is accomplished by special gear. Separate bolts are used for securing the main bearing caps. The practice of using the through bolts for the double function of relieving the framing of the working loads and acting as main bearing bolts cannot be recommended.

Another point worthy of mention is that the main bearings in all large engines are of the normal rectangular shape, but with this difference, that the entire removable part consists of a rectangular shell, in which is fitted semicircular white-metalled bushes. These bushes can be turned out of the engine and remetalled without lifting the crankshaft. The rectangular shells can also be lifted as occasion requires, and liners placed between them and the bedplate, so as to bring the crankshaft back to its original alignment. If circular bushes only are fitted, these must be remetalled every time it is necessary to realign the crankshaft. This is a big job, and engineers are apt to run their engines too long, until the crankshaft is so much out of line that high stresses are set

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up which may ultimately cause fractures. Although this construction is perhaps a little more costly than that generally adopted, it has worked well in practice. The type of bearing is illustrated in detail by Fig. 27.

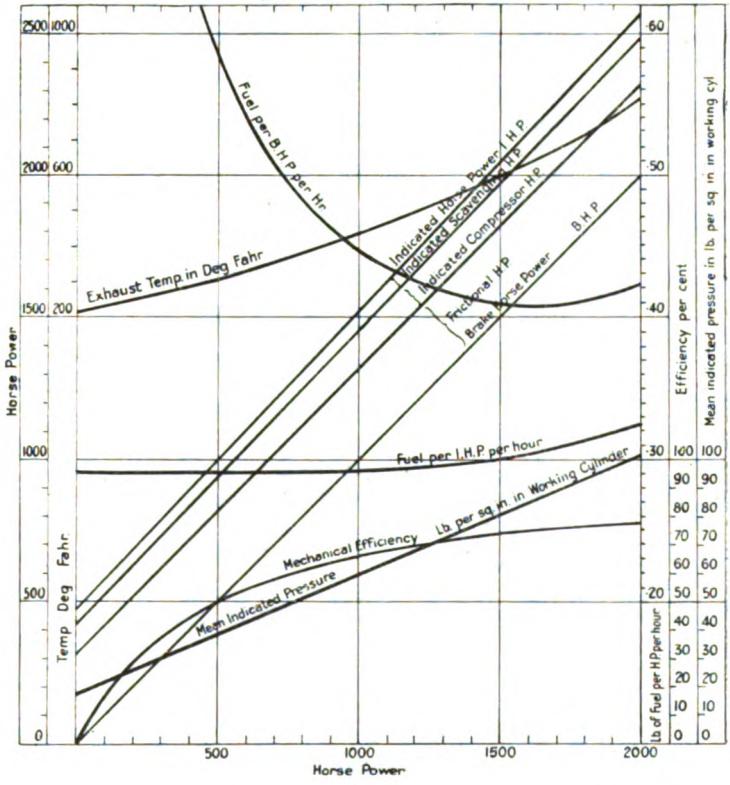
Horse Power
Temp Deg Fahr
Efficiency per cent
Mean indicated pressure in lb. per sq. in. in working cyl.
Lb. of fuel per H.P. per hour
Horse Power
Fuel per B.H.P. per Hr.
Exhaust Temp in Deg Fahr
Indicated Horse Power I.H.P.
Indicated Scavenging H.P.
Indicated Compressor H.P.
Frictional H.P.
Brake Horse Power B.H.P.
Fuel per I.H.P. per hour
Mechanical Efficiency
Lb. per sq. in. in Working Cylinder
Mean Indicated Pressure

Fig. 28a.

Figs. 28a to 28d give details of a characteristic test on a propelling engine. These refer to Type L.684, developing 1,600 b.h.p. at 100 r.p.m. in four cylinders, each of 680 mm. diameter by 1,100 mm. stroke, and similar to Figs. 22, 23, and 24, two of which are installed in the motor-tanker "Ardor," owned by the Italian associated company of the

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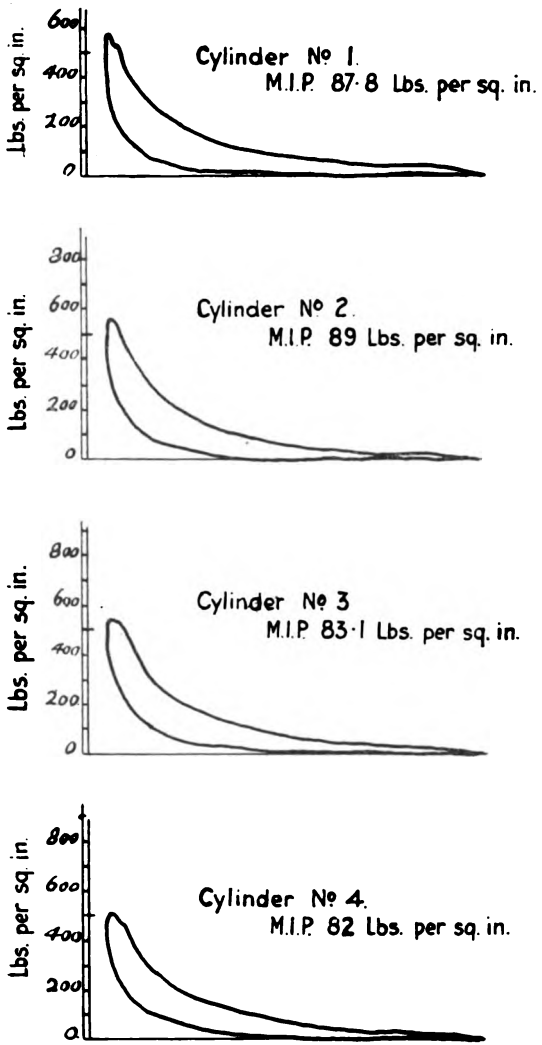

Fig. 28b.—Indicator Diagrams for the Working Cylinder.

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Standard Oil Co. The diagrams and curves are self-explanatory, and require no comment.

Fig. 29 is given as an example of easy overhauling. The

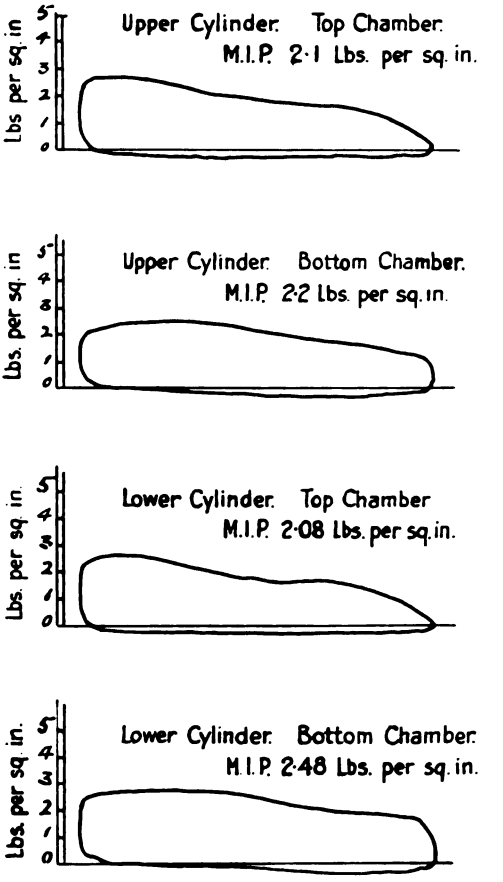
Lbs per sq. in
Upper Cylinder. Top Chamber.
M.I.P. 2·1 Lbs. per sq. in.
Lbs. per sq. in
Upper Cylinder. Bottom Chamber.
M.I.P. 2·2 Lbs. per sq. in.
Lbs. per sq. in.
Lower Cylinder. Top Chamber
M.I.P. 2·08 Lbs. per sq. in.
Lbs. per sq. in.
Lower Cylinder. Bottom Chamber.
M.I.P. 2·48 Lbs. per sq. in.

Fig. 28c.—Indicator Diagrams for the Scavenging-Air Pump.

valve gear is so designed that when the holding-down nuts of the cylinder cover are removed, the cover complete with all gear can be lifted away and the piston withdrawn. There are no large inlet or exhaust pipes, or manœuvring shafts to dis-

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connect. Three men can remove a 16-inch diameter piston in 20 minutes, and four 27-inch diameter pistons can be removed and examined in a forenoon.

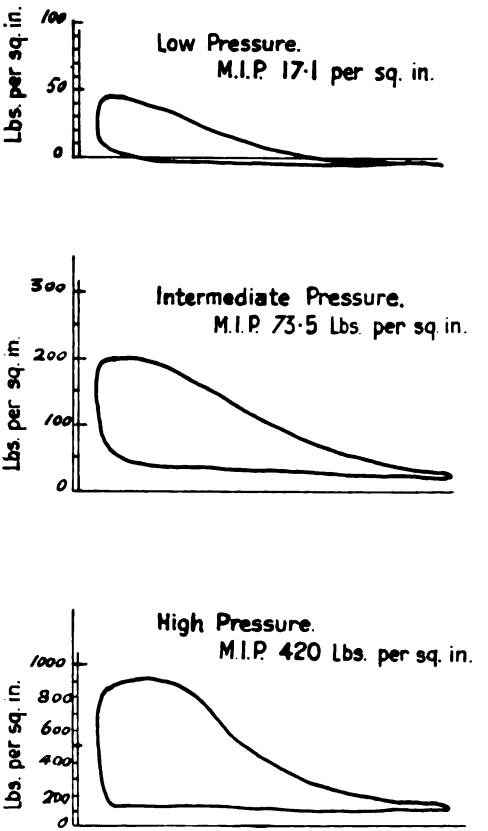

Fig. 28d.—Indicator Diagrams for the Air Compressor.

Many other ships have been fitted out, extending over a number of years, but only a representative few have been mentioned, in order to make the paper a connected historical sketch.

Some time after the war, as a result of the demand for

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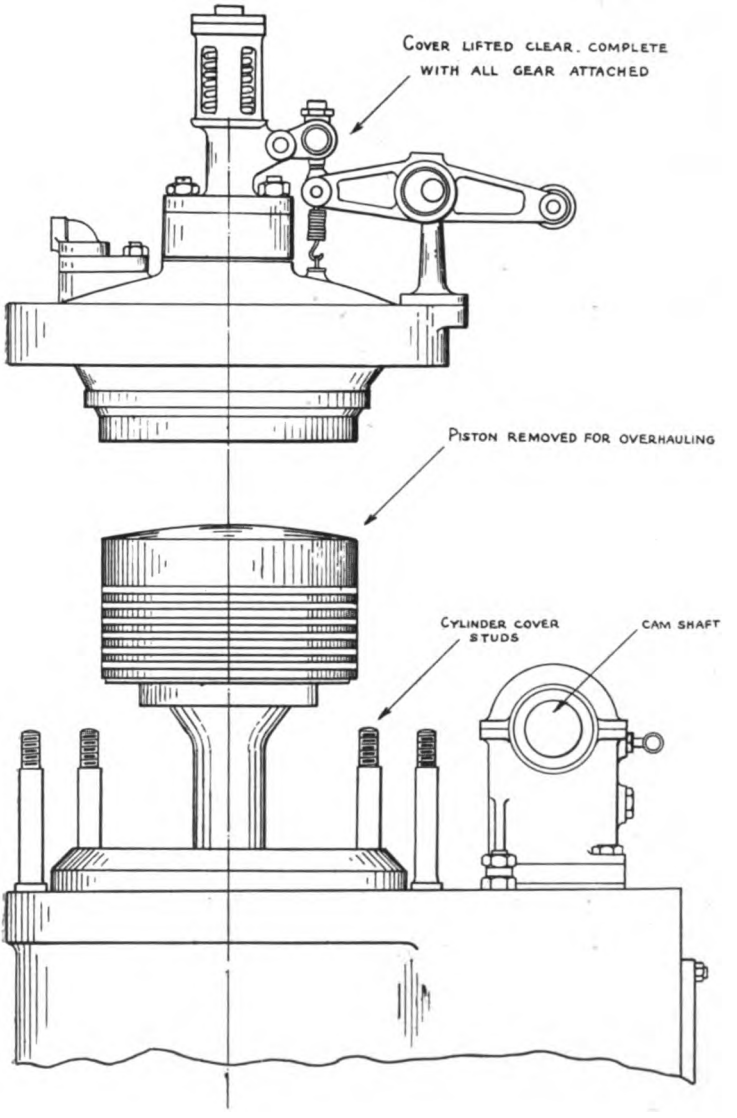

Fig. 29.

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increased powers, most of the large companies turned their attention to perfecting the double-acting engine, the Fiat Co. as before adhering to one of the two-stroke type. The advantages of this engine over the four-stroke double-acting engine are just the same as the advantages of the single-acting two-stroke engine over the single-acting four-stroke engine, and need not be reiterated.

The construction of a single-cylinder engine was commenced in 1925, and by the spring of 1926 it was running successfully on the test bed, and is now completely out of the experimental stage. The cylinder has a bore of 840 mm., the stroke being 1,000 mm. It is the most powerful completed experimental unit. Continuous tests have given such high powers that engines can now be supplied having cylinders of the above dimensions and developing from 1,600 to 1,700 b.h.p. per cylinder for normal services, or 2,000 b.h.p. per cylinder for large fast vessels. This engine can be built with three, four, six, or eight cylinders under the usual guarantees of performance, so that powers up to 16,000 b.h.p. on one shaft are available. Fig. 30 illustrates the single-cylinder unit on test, and Fig. 31 is a section from which the principal features of construction may be seen. Generally speaking, the walls surrounding the combustion chamber follow very closely the successful practice of the single-acting engines, and sufficient has already been said about the other constructional features, many of which are embodied in the double-acting engine, to enable the design to be appreciated.

In all engines the design of the telescopic tubes is generally a difficult problem, and particularly so in those of the double-acting type. In the design of gear hitherto fitted on double-acting engines there has always been some undesirable features. In many cases the gear is placed inside the crank-chamber, and as water is generally used as a coolant for the pistons, mixture of this coolant with the lubricating oil cannot be entirely eliminated, no matter what is done. The telescopic tubes get splashed with the lubricating oil, which is then carried into the water-cooling cylinders, where it is washed off and dis-

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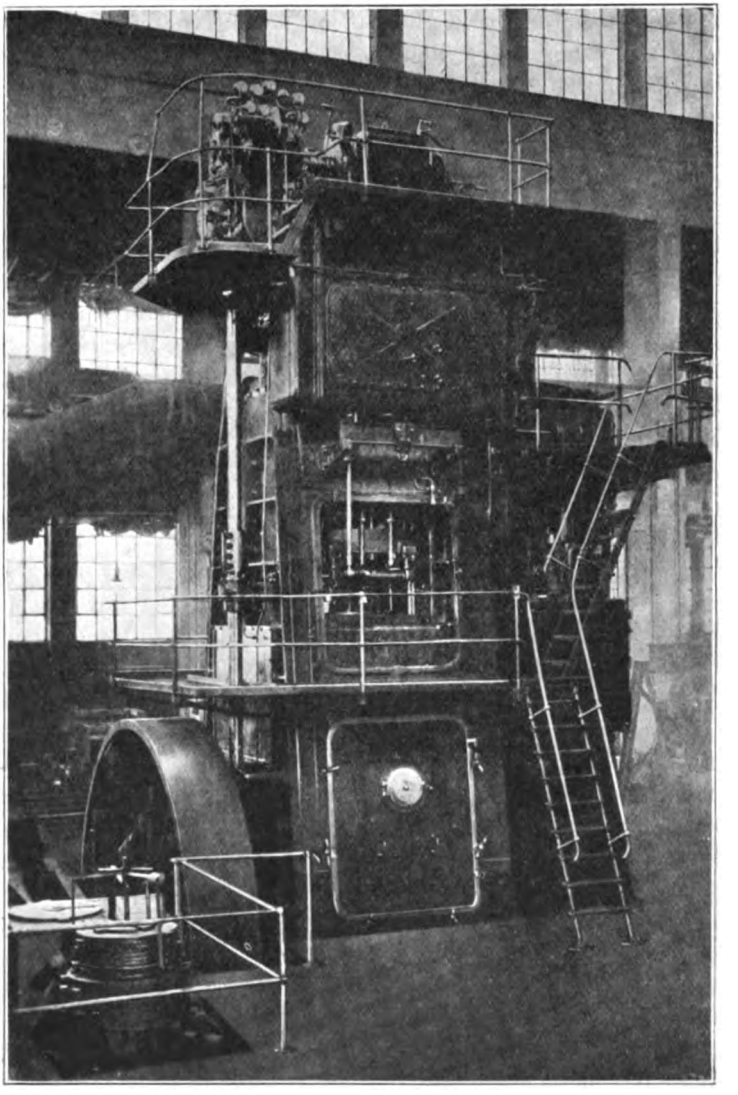

Fig. 30.—Double-Acting Experimental Engine.

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charged overboard if the cooling is by salt water, or into the double-bottom if the cooling is by an internal system. In some cases the water cylinder is arranged outside of the crank-chamber, but the telescopic tubes alternately enter the water cylinder and the oily atmosphere, and the loss of oil has not been overcome. In the system evolved, Fig. 32, two tubes are used for the inlet and two for the outlet. It is to be noted that one tube of the outlet and one of the inlet work in the atmosphere in the crank-chamber, and the other tubes are working in the cooling-water cylinders. By this means any mixing of the lubricating oil and cooling water is entirely avoided. It is well known that a mixture of lubricating oil and salt water facilitates carbonisation on the internal surfaces of the piston. On an engine which suffered from this defect, an analysis of the deposits taken from the internal spaces showed that they contained more than 80 per cent. of sea salts. In view of this, it is extremely important that no mixture of salt water and lubricating oil should be circulated through the pistons.

In addition to main propelling-engines, smaller engines for auxiliary purposes have been developed as a result of long experience in submarine construction, and a motor embodying all the features of great accessibility, steady running, and high output is now available. As a rule, all engines over 100 h.p. per cylinder are fitted with crossheads, but as an example of a trunk-piston type of lower output, a short description of an engine developing 240 b.h.p. when running at 270 r.p.m. will be given. This engine is illustrated by Figs. 33 and 34. There are four cylinders, each of 9·8 inches diameter by 17·7 inches stroke, and the engine is self-contained, having its own scavenging pump, air compressor, and circulating pumps. The water pumps are of the ordinary reciprocating type, but for the forced lubrication and piston cooling the pumps are of the rotary tooth type. The camshaft is placed in the crank-chamber, where it can be copiously lubricated, and is driven by spur wheels of the ordinary type from the crankshaft. The inlet and outlet to the scavenging pump are controlled by a piston

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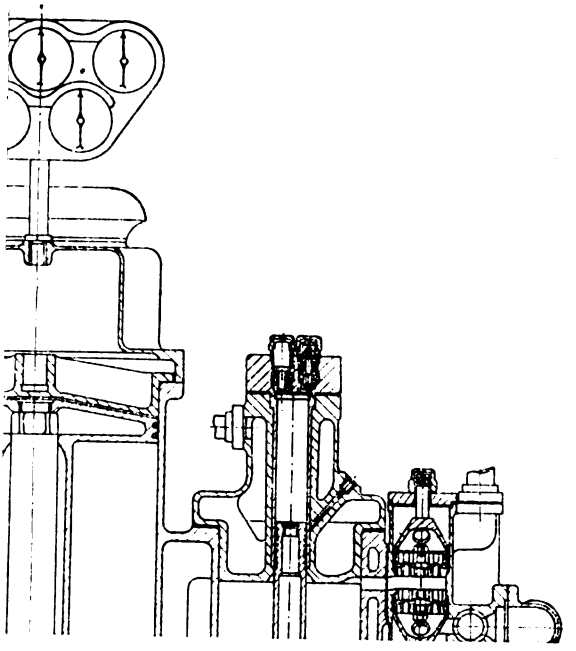

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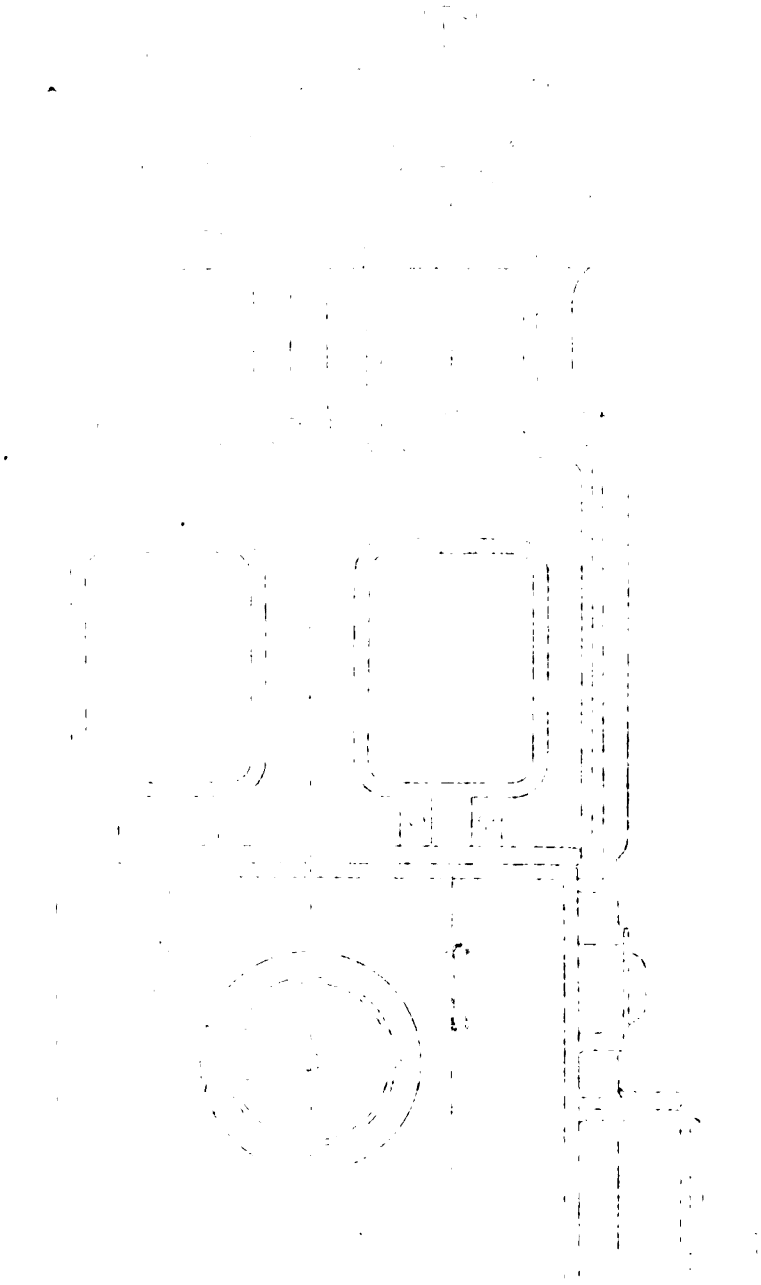

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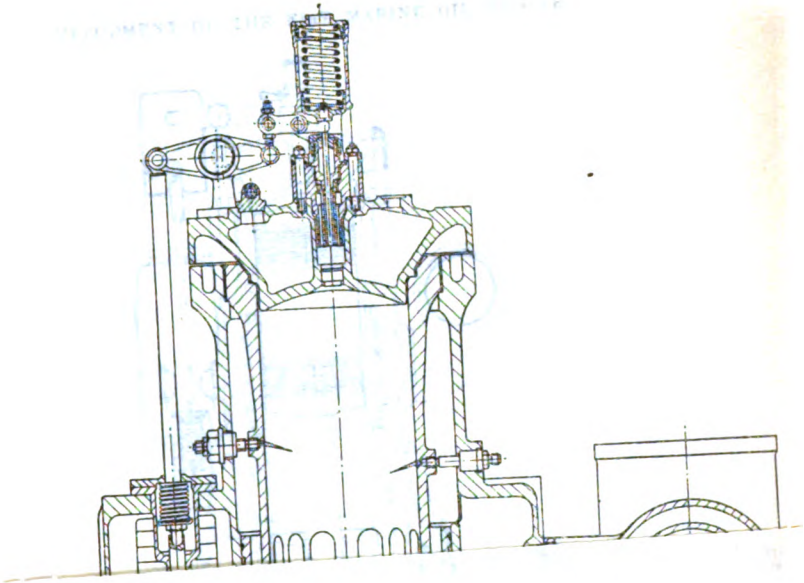

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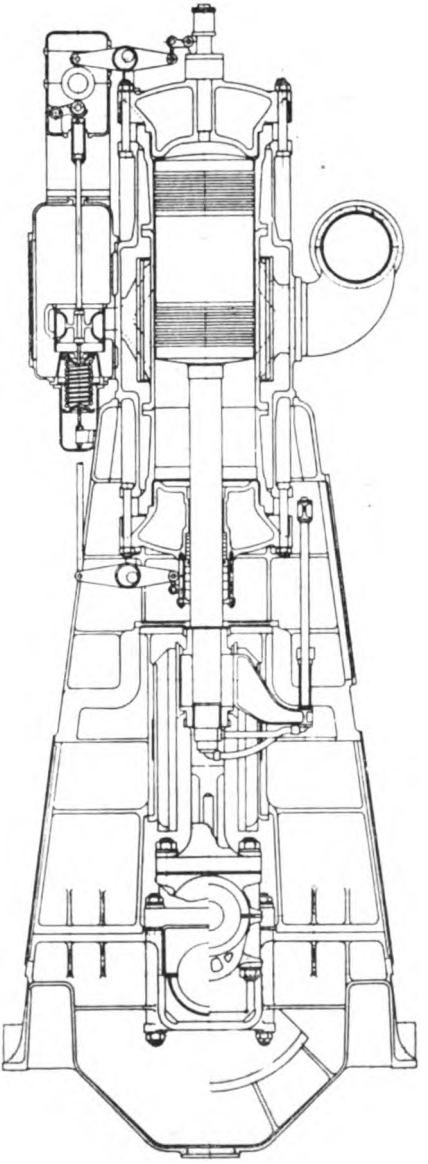

Fig. 31.

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valve positively driven from the crankshaft. Ordinary automatic valves made from thin steel plate are very liable to crack and give trouble in the case of high-speed engines. The air compressor is of the ordinary three-stage inter- and after-cooled type, having automatic valves in all stages. The oil cooler is neatly incorporated in the bedplate, and is very accessible for cleaning purposes. There are, of course, no water joints inside the crank-chamber. This type is built in two, three, four or six-cylinder models.

The construction of fast motor-liners has brought about a large increase in the power of auxiliary sets, and a special type has been designed which is particularly suitable for cases where vibration must be eliminated. This type also possesses all the latest features, such as separating the cylinders entirely from the crank-chamber, as described for the 2,200 b.h.p. slow-speed engine. Fig. 35 shows a three-cylinder 450-b.h.p. engine in section. The cylinders are 400 mm. in diameter, and the stroke 500 mm. Four of these sets are fitted in the "Bermuda," owned by the Bermuda and West Indies Steamship Co., Ltd. Fig. 36 shows a characteristic set of test data curves from one of these engines, from which it will be noticed that the fuel consumption is just under ·4 lb. per b.h.p. per hour. The arrangement of the moving masses of this engine is such that primary and secondary balance is complete. In fact, the disturbances are too small to show on any diagram to a reasonable scale. The same design of engine may be applied to main propelling purposes for high-speed yachts and other light craft.

Taking advantage of the pioneer work done by others in connection with hot-bulb engines, and combining it with their own extensive experience of pure Diesel engines, in 1922, the Fiat Co. evolved a new design of hot-bulb engine, possessing none of the disadvantages of the crank-chamber compression type. Engines of this type which are required for hard and continuous service have always been handicapped by crank-chamber compression. Fig. 37 shows a section of the type of engine, from which it will be noticed that it is fitted with

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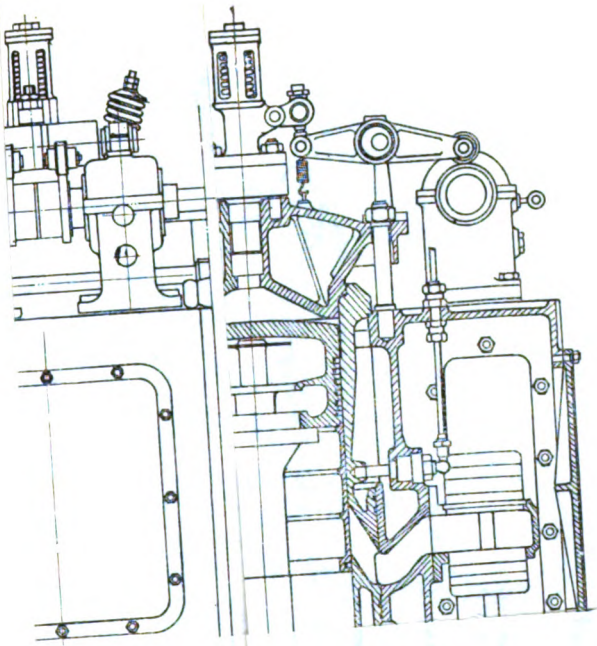

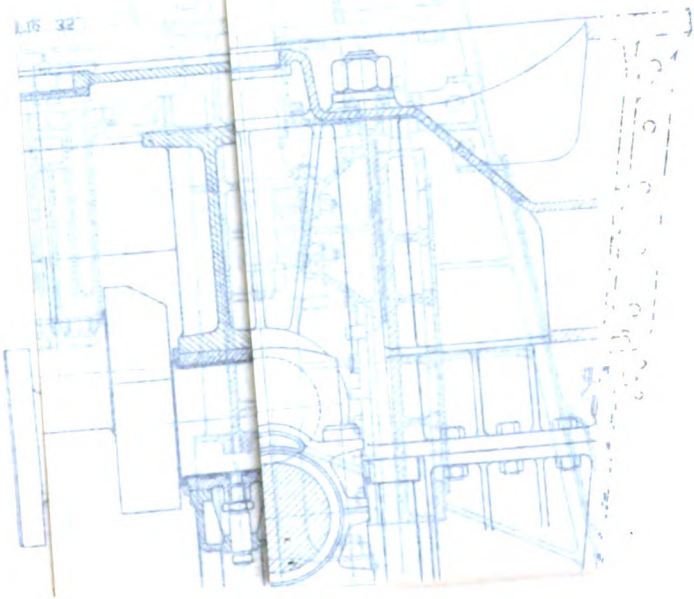

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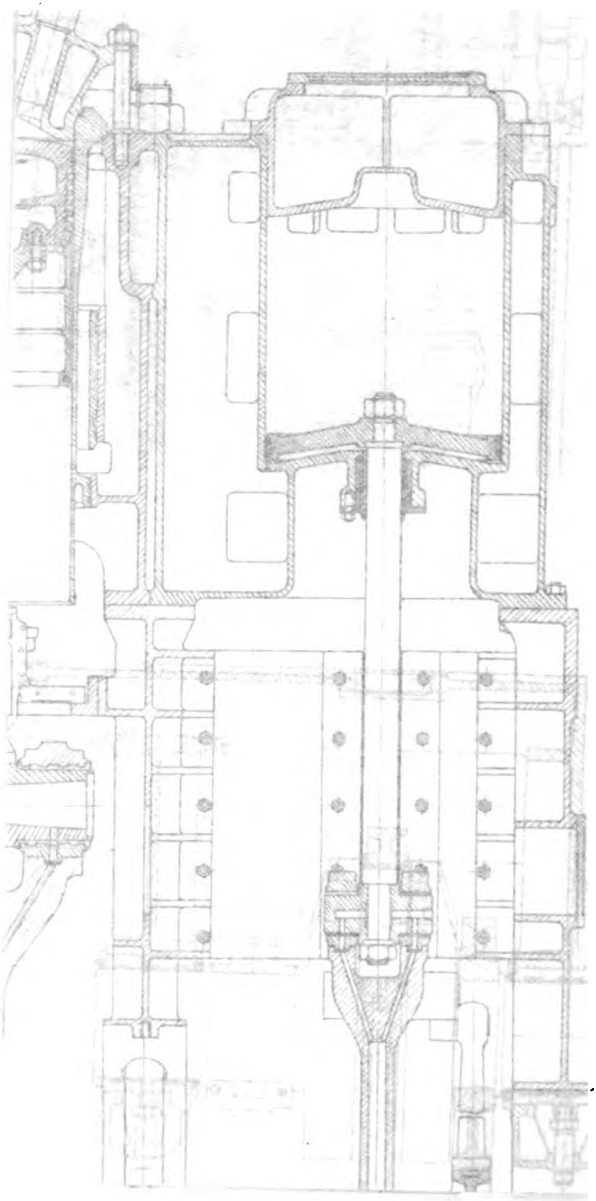

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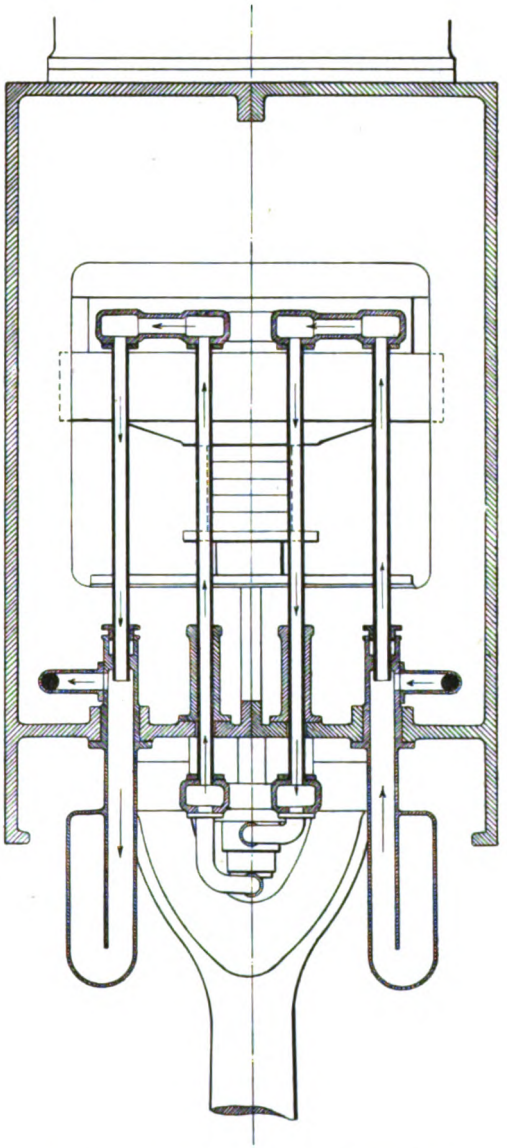

Fig. 32.—Arrangement of Piston-Cooling Gear.

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crossheads, and has the cylinder entirely separated from the crank-chamber.

The scavenging air is compressed on the under side of the piston, which has a piston rod that passes through a stuffing-

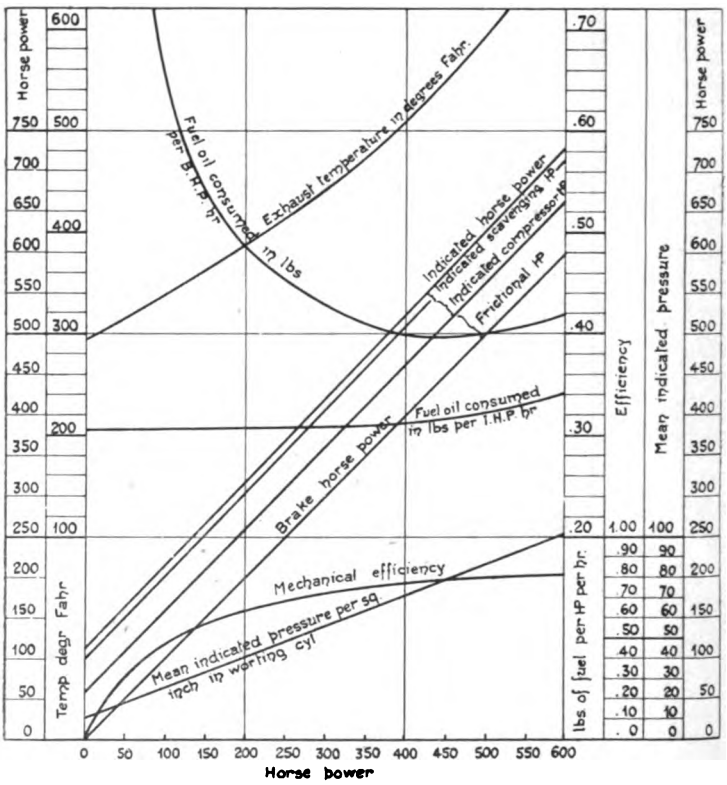

Fig. 36.

box into the crank-chamber, so that the whole of the running gear can be copiously lubricated from the forced-lubrication system without danger of any of the oil being carried by the scavenging air into the working cylinder. Whilst the fuel-oil consumption of any hot-bulb engine is not particularly low, the construction here outlined enables the lubricating-oil con-

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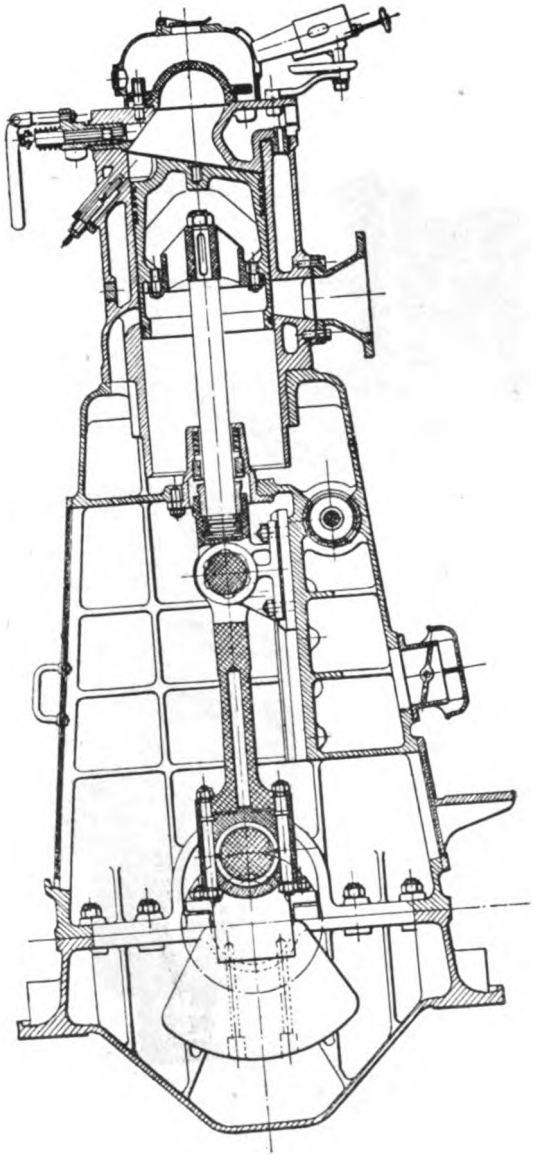

Fig. 37.

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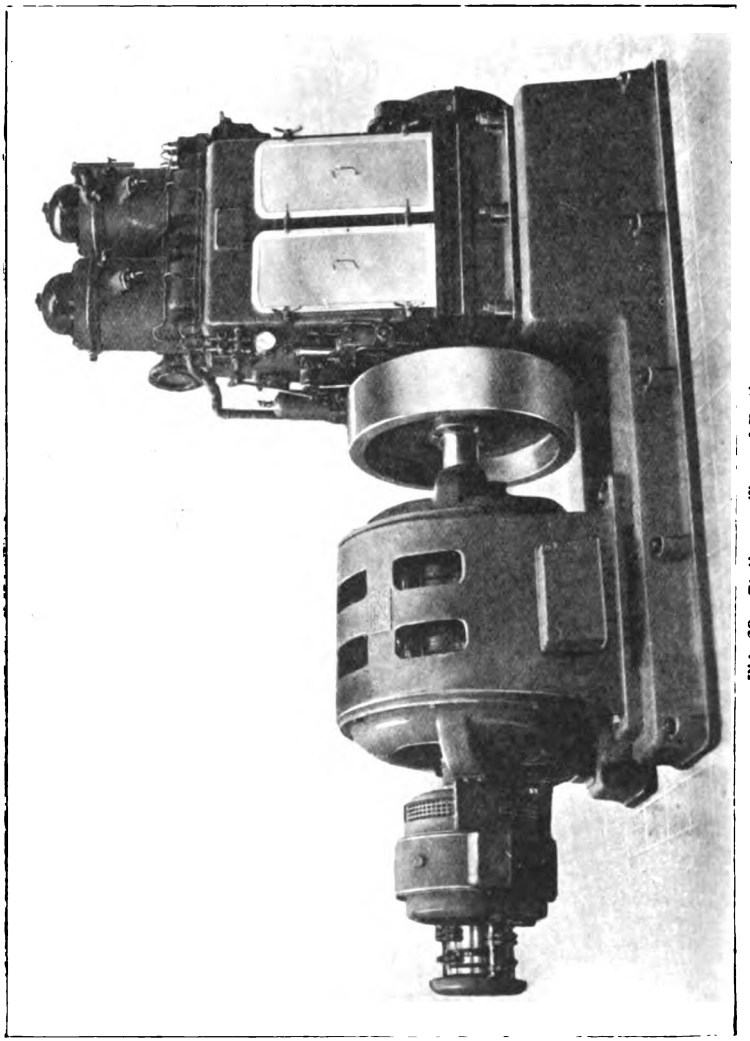

Fig. 38.—Stationary Type of Engine.

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sumption to be reduced to quite a normal amount, and for the present engine it is not more than ·006 lb. per b.h.p. per hour.

A rotary valve operated by an eccentric from the camshaft is placed in the inlet passage in the framing. The object of this is to control exactly the amount of air to the amount of fuel for any particular load, so that the combustion remains constant for all powers and speeds. By this means the bulb is kept at a uniform temperature, and no misfiring occurs for the whole range of output. The desirable feature of eliminating the water drip is also obtained. Fig. 38 illustrates one of these sets driving a generator for auxiliary purposes on board ship. They can be fitted with electrical starting-gear if necessary and are adaptable for any small purposes on sea or land.

Discussion.

Mr. J. R. HUNTER: There is little in the paper to discuss, for, as is usual with Mr. Shannon's contributions, everything is set out in his own particularly decisive manner, backed up by the foremost thinking and experiments of modern oil engineering. The opening sentences of the paper regarding the recording of reasons for procedure are worthy of special note, and doubtless one of the most interesting libraries of modern times would be a history of the development of engineering products written up by the technical experts of the various manufacturers.

If a paper on the Fiat engine of to-day had been put forward as a proposal, without the historic facts associated with it, there is no doubt that a tremendous amount of discussion would have been forthcoming, but, as the steps leading up to its present design have been clearly outlined by Mr. Shannon, and the assertion made that what is offered is entirely constructed on accumulated experience gained over a considerable period of years, the critic is apt to be wary of entering into any discussion. The engine has many outstanding features in its modern design, one of them being the flat-bottomed main-bearing block with its combined half-circular bush, which

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Mr. J. R. Hunter.

without doubt is something the sea-going engineer will welcome. I have seen a similar design to this elsewhere, but with the addition of a wedge-shaped piece inserted below the flat-bottomed block for adjustment in place of liners. This wedge-shaped piece is, of course, more expensive in machining and fitting operations, but must, when properly used in conjunction with a bridge gauge, prove a boon to the engineers responsible for the crankshaft alignment. The remarks in the paper concerning the long stay-bolts passing down from the cylinder top to the bedplate are worthy of particular note, especially regarding the use of these as main-bearing bolts. Movements of the upper structure of the engine can be traced to such usage, and it is obviously not good practice.

The Fiat system of telescopic pipes for piston cooling is ingenious, and seems to point the way to the elimination of many well-known troubles, which, up till now, do not appear to have been overcome, judging by the enormous number of patents which have been taken out. Regarding this Fiat arrangement, I should like to ask if any crosshead arrangement has been tried at the top of the moving pipes, and also if any troubles were experienced in the initial stages due to the floating action depending on the alignment and the working clearances of the main engine crosshead. The pipes joining the telescopic gear to the bottom of the main piston rod seem to be quite ordinary, but I know of instances where such pipes were a source of trouble, and, though this latter may have been due to the particular type of engine to which they were fitted, it would be interesting to know if the Fiat Co. have experienced anything of this sort, in view of the fact that they have quite an easy way of overcoming such a difficulty by using the very substantial cantilever arm which holds the moving tubes.

Mr. K. O. Keller: On page 670, Mr Shannon states that the primary and secondary balance is complete. I shall be glad if he will furnish the balancing diagrams to confirm his statement, as it appears that secondary balance cannot be obtained, neither for force nor for couples.

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Mr. W. C. MacGibbon.

Mr. W. C. MacGibbon (Member): Mr. Shannon puts forward some new ideas, especially in connection with the water-cooling of cylinders in two-stroke engines. Many have been under the impression for a long time that the right thing to do was to cool a two-stroke engine quickly.

I am afraid I cannot follow Mr. Shannon's argument when he says, on page 643, "The good thermal conditions of the two-stroke engine are also proved by the heat transmitted to the water, which is very moderate, and less than in the case of the four-stroke engine." Even if the period is one-third of the cycle in the two-stroke and one-fourth in the four-stroke engine, one cycle is completed in half the time of the other. During the working stroke, the conditions are very similar in both engines for producing heat and for heat transmission through the cylinder liner, so this need not be considered. The same applies during the compression stroke, so that it is only necessary to deal with the two idle strokes of the four-stroke engine. During the exhaust stroke, heat is passing through the liner to a small extent, and this is also true in both engines during the compression stroke. If it is a fact that the usual m.i.p. in two-stroke engines is considerably less than in four-stroke engines, is this not due to the difficulty with the latter in keeping the cylinder cool, so that it is not always useful to retain as much heat in the cylinder at the wrong period, as is the case in the two-stroke engine?

Would it be possible to have a test carried out under the auspices of our Institution on the two types of engine? It might be possible to induce a Clyde firm to allow the investigation to be made. The engines to be tested should be as nearly as possible of the same dimensions and run at the same revolutions, and should be tested at the same m.i.p. The data would be very valuable to the designers of both types. The question is when to keep heat and when to release it, but that is not a new fact in engineering.

Mr. Robert Love (Member): Being associated with the construction of the two-stroke engine, Mr. Shannon naturally

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Mr. Robert Love.

considers the four-stroke engine out of date; but judging from the general tendency to apply supercharging to the four-stroke engine, thereby enabling higher mean pressures to be carried in the cylinder with a corresponding increase of power, it would appear that the four-stroke engine will remain a competitor for some time yet. No doubt the ultimate standard design will be a two-stroke double-acting engine, possibly embodying some of the good points of the Fiat engine.

Mr. Shannon states that "with two-stroke engines, the inertia of the reciprocating masses is balanced at the top dead-centre by the pressure on the piston." In the four-stroke engine this does not occur, but instead of being a disadvantage, it is of assistance in ensuring satisfactory lubrication of the main bearings, and the bottom and top end bearings. This feature of the two-stroke engine was directly responsible for the unsatisfactory operation of the early engines of this type fitted with drip lubrication to the bearings.

Mr. Shannon also refers to the cylinder head of the four-stroke engine with its various valves as being complicated, whereas the two-stroke engine has a simple cylinder head. On the other hand, if cylinder liners be compared, it will be seen that the four-stroke engine has a simple casting without ports, while the two-stroke engine has a complicated casting with ports subjected to high temperature on the exhaust side and low temperature on the scavenging-air inlet side.

The reference to the method of comparing the loading of engines by the amount of fuel burnt per unit area of piston is, to a certain extent, misleading. This method I have found quite satisfactory, and is a quick way of comparing the loading of engines of the same type when operated by approximately the same piston speed. The method adopted by the Fiat Co. of testing their engines from 40 to 50 hours at an overload of 40 to 50 per cent. is surely unusual, and would point to the engines being very moderately rated at normal load. The statement that twelve two-stroke high-speed engines, each of 2,500 b.h.p., are being built for Italian submarines is interesting, and in view of the

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four-stroke type having been generally used for this purpose, can Mr. Shannon give any indication as to the number of four-stroke engines under construction in that country for similar duties?

The diaphragm plate fitted between the cylinders and crank-case in the crosshead type of Fiat engine is an improvement over the usual two-cycle construction, but entails extra height and weight.

Mr. JOHN S. BROWN, M.B.E. (Member): This paper traces the evolution of the marine oil-engine as seen by an organisation which has adhered throughout to the principle of the two-stroke working cycle. In its early days the two-stroke engine presented a series of problems of its own, and it is interesting to see how these have been gradually mastered to permit of the construction of the double-acting unit of 2,000 horse-power, which is illustrated in Figs. 30 and 31. It is perhaps unfair to let our interest concentrate on that unit alone; but it is disappointing to find that no information is provided on the performance of this engine. Can we not be told whether it has had, say, a month's actual running between the spring of 1926 and to-day, and what information it has given on piston rods, on combustion spaces, and on fuel injection?

The scavenging arrangements in the Fiat engine have always been distinctive, and it becomes of great value to have this record of experience with different forms of ports. But all the engines illustrated show the solid-forged type of crankshaft—a form which is generally associated with engines constructed to comply with restrictions on the weight and space. The performance curves in Fig. 28a require the addition of the r.p.m. to make them understandable. Further, will Mr. Shannon confirm that the units are horse-power, and not the smaller Continental quantity defined as "force-de-cheval," which it is not legitimate to translate?

The section on the thermal stresses in the cylinder parts leads to a conclusion which is quite contrary to all my experience, and I think that there are many others who will consider the suggestion of a misunderstanding as quite misplaced.

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Mr. John S. Brown, M.B.E.

It might be legitimate to introduce ballistical data if information is unavailable from actual engine trials; but this subject has already arisen before the Institution, in 1921, and I then put on record* results from an engine which enable direct conclusions to be drawn. However, on a basis of ballistics, it does not seem necessary to proceed beyond the question of whether a Maxim gun increases in temperature with augmented rates of fire. It does, for firing may have to stop to allow the gun to cool; and correspondingly, a two-stroke cylinder will reject more heat to the cooling water than a similar four-stroke cylinder, operating at the same m.i.p. and speed. Mr. Shannon's conclusion would suggest that these heat quantities are identical; thus it is not completely supported by ballistics. Turning to the engine records referred to above, it is shown that when the engine speed is doubled there is a 50 per cent. increase in the heat flow quantities; and, believing that the heat flow is confined to the combustion period, this means that a 50 per cent. increase in the heat flow occurs on doubling the number of working cycles. In other words, a two-stroke engine may develop twice the power of a four-stroke engine, due to the increased number of working cycles, but the thermal stresses in the two-stroke engine will then be 50 per cent. in excess of those in the four-stroke engine. Taking the figures quoted in the paper, it would seem that the two-stroke engine is to be operated at an output of 150 per cent. of the four-stroke engine. My figures suggest that the heat stresses in the two-stroke engine will then be about 125 per cent. of those in the four-stroke engine. This figure is different from both the one which Mr. Shannon sets out to disprove and the one at which he finally arrives; but it has the merit of being derived from the records given by a Diesel engine, and I would ask whether it is not also in accordance with Mr. Shannon's experience.

Mr. A. D. Bruce: The only occasion on which I saw a Fiat engine was on the "Ansaldo San Giorgia" when she

* Trans. of the Institution, Vol. lxv, p. 74.

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Mr. A. D. Bruce.

first came to the Clyde in 1919. I was then greatly impressed with that engine, as it was like the Sulzer type in many respects, although it has now changed somewhat. The adoption of the cylinder oil tray at the top of the crank-case is one difference. Most of the four-stroke engine makers adopted that contrivance long ago, and although it is not new, it is certainly a very important detail which prevents crankcase oil from becoming contaminated by unburnt fuel and cylinder oil. It seems to me that it would be advantageous if Messrs. Sulzer Bros. adopted it, as much for keeping the crankcase lubricating oil in good condition as for preventing the piston-cooling water from leaking into the oil in the crank-chamber. One good feature in the Fiat engine which Mr. Shannon illustrates is the flat-bottomed main bearing. I cannot understand why so many Diesel-engine makers retain the circular-bottomed bearing, because in the case of the shaft wearing down it cannot be brought back to the original centre line without being remetalled; but with the flat-bottomed bearing, liners of the required thickness can be inserted.

Another important point associated with Diesel engines having steel columns which pass from the bottom of the bed-plate to the top of the cylinder beam, and having these screwed and fitted with nuts in the vicinity of the main bearing covers to keep them in place, is the considerable stretch in the columns due to the gas pressure, and the nuts for the main bearing covers, being threaded on, the columns give a certain amount of accidental clearance to the main bearings, the crankshaft moving up and down to this extent. We are all convinced of the value of rigidity in Diesel engines, and it is absolutely essential in the framing. Therefore, it seems to me a good feature in the Fiat engine to have the main-bearing bolts separated from the steel columns.

Mr. Shannon states the reasons why the Fiat Co. decided to keep to the two-stroke engine, but I am not quite clear what limitations he refers to when he says "Larger powers can be developed by the two-stroke engine, without the limita-

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Mr. A. D. Bruce.

tions met with in the four-stroke engine which have recently made builders adopt some compromise in their designs." Is the limitation that of the exhaust-gas temperature, and the effect it has on the exhaust valves and seats, or some other feature, the compromise being supercharging? I should be glad if he would explain that point more fully.

The fuel coefficients mentioned on page 640 are very useful for comparative purposes. Mr. Love points out that, in the case of Messrs. Beardmore & Co., these factors were used on the understanding that the piston speed was constant.

Mr. Brown mentions the paper* I read in 1921, and I recall his contribution to the discussion, which included some valuable data in connection with the heat passing through the cylinder and piston walls. Unfortunately, I have not been able to experiment further in this connection, and unless the opportunity presents itself of carrying out experimental work and determining points at issue, it is not of much value to keep on theorising in a general way. For instance, in making an analysis, if it is impossible to determine the exact value of each item, then the ultimate effect cannot be appraised.

It is rather astounding to read on page 643 that the heat flow through two-stroke cylinder walls is about 25 per cent. less than that flowing through four-stroke cylinder walls, and one is reluctant to accept the statement without further consideration. It occurs to me that, in the two-stroke engine where there are more impulses in a given time, from the pressure point of view the material is having a rather worse time than in the case of the four-stroke engine, and there are more applications of the maximum temperature, which causes an earlier deterioration in the material. Further consideration may lead to the conclusion that possibly a difference in the heat flow of 25 per cent. between the two- and the four-stroke engines is not the most important factor, because the design of the cover, its contour and passages, may not be quite what they should be, and the material may not be the most suitable nor have been handled in the foundry

* Trans. of the Institution, vol. lxv, p. 17.

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in the best possible manner. These conditions apply to both the two- and four-stroke engines, and are possibly more important than the difference of 25 per cent. in the heat flow.

Mr. CHARLES RETTIE: I should like to express my appreciation of Mr. Shannon's paper and the many interesting points raised, particularly in connection with his opening remarks on the filing and recording of special information. I am looking forward to the early opening of branches of the newly-formed Association of Special Libraries, which has been started in London to facilitate the co-ordination and systematic use of sources of information in science, industry, etc. The description of the Fiat engine on page 656, and the reference to its overload capacity, has interested me. Having devoted some attention to the electrical propulsion of ships, I should be glad if Mr. Shannon could supply any information concerning the engines turned out by his firm for the same purpose. The history of the development of the electric drive in this country is not good, and the fault has been attributed to the inability of Diesel engines to take the overloads that are thrown on the generators during rough weather.

Mr. JAMES CALDERWOOD: The interesting review of the development of the Fiat engine submitted by Mr. Shannon is of considerable value to engineers, as it points out features that have been tried and found unsatisfactory, and so may prevent, to some extent, overlapping, which has so often occurred in engineering research. There are, however, a few points raised in the paper on which I do not altogether agree with Mr. Shannon. A paragraph on page 622 leaves the impression that of the two-stroke engines on order at present the majority are of the Fiat type. I think it is only fair to point out that two-thirds of the total power of marine two-stroke engines at present under construction are of Sulzer design. Like the Fiat, the Sulzer marine engine has always been of the two-stroke type, and its development started in 1907, shortly before the first Fiat engines were built.

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Mr. James Calderwood.

I agree with Mr. Shannon that for ship propulsion an engine must be designed to meet marine requirements, and not be regarded as a modified land type. At the same time, the value of experience with land engines must not be underrated, particularly where engines of high power per cylinder are concerned. The reliability of such engines in respect of heat stresses can be tested out in safety on land, where a break-down will not be of such serious consequence as it would be at sea. After satisfactory service in continuous full-load running on land, a new cylinder size can safely be adopted for marine work. It is principally in the engine framing that the marine engine must have special attention. Here the utmost rigidity is, as Mr. Shannon says, of extreme importance.

I cannot agree with Mr. Shannon's statement that the scavenging ports, of a height equal to the exhaust ports, are as satisfactory as the arrangement with an upper row of scavenging ports slightly higher than the exhaust. General experience has shown that with the latter port arrangement a much higher overload can be carried with good combustion, while at normal loads combustion is better and cylinder temperatures lower than when scavenging and exhaust ports of equal height are adopted.

On page 654, Mr. Shannon comments adversely on the lubrication of piston skirts which run into the crank-chamber. His remarks are, however, purely academical, and no difficulty has been experienced in practice with piston skirts of the design shown in Fig. 25. Further, if an efficient arrangement of wipers and lantern ring is fitted at the bottom of the cylinder liners, very little cylinder lubricant is carried down into the crank-chamber, and if the fuel combustion is good, the effect of this small quantity of cylinder lubricant is only to discolour the bearing lubricating oil without detracting from its lubricating properties. The only type of engine in which pistons running into the crank-chamber are unsuitable is in small engines running at a fairly high speed, where there is some loss of oil due to splashing on to the piston skirt. For this reason, it is advisable to use the type of construction

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with piston-rod glands separating cylinders from crank-chamber in engines running at speeds higher than 200 r.p.m.

Fig. 26 is definitely misleading. If the section 26a had been taken in the other direction, it would have shown the three openings in the Fiat cover, as compared to the single central opening in the Sulzer cover shown at 26b. The Fiat cover seems to be a poor shape from heat-stress considerations, as the heated surface is not free to expand as it is in a cover which is designed as a solid of revolution. The use of steel for the covers will tend to increase rather than reduce heat stresses, unless the material is much thinner than is shown on any drawing reproduced in the paper.

The overload spoken of as the "absolute maximum" does not seem to indicate good scavenging, as it corresponds to an m.i.p. of only 105 to 110 lbs. per square inch. Two-stroke engines with good scavenging can run at about 125 lbs. per square inch m.i.p. with perfect combustion and a clear exhaust, and most four-stroke engines can run at about the same figure. Such good scavenging as is indicated by these mean pressures ensures low working temperatures and heat stresses at normal loads, whereas in the Fiat engine, if the scavenging is only good enough for a maximum m.i.p. of 110 lbs. per square inch, the temperatures and heat stresses at normal loads must be much higher than in engines with efficient scavenging.

Mr. SHANNON: I wish to thank Mr. Hunter for his generous and constructive criticism of the paper. I also have studied main bearings having a wedge-shaped piece for bringing the shaft back to its original alignment when wear has taken place. The idea has always appealed to me, and it is rather difficult to know why it has fallen into disuse. It would appear quite safe in the hands of experienced and careful engineers, but it is possible that the chances of its accidentally slackening back when the engine is working has ruled it out of the safe and sound practice considered necessary for marine oil-engines or marine machinery of any kind.

The only performance data available in connection with the

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Mr. D. M. Shannon.

telescopic arrangement of tubes are those obtained on the double-acting experimental engine. Originally the upper cross-head portion was provided with guides, but all the running has been done without them, and they will not be fitted to any future engines. It might appear that the arrangement would be difficult to align properly, but this point is common to any type of telescopic tube. I can only say that the Fiat Co.'s experience with this gear has been uniformly good, and it will be adopted on all engines of large type. I cannot record that any trouble has been experienced with the pipes joining the telescopic gear to the bottom of the main piston-rod.

I am afraid that no good purpose would be served by publishing the balancing diagrams requested by Mr. Keller. I could only show a series of closed vector polygons for both primary and secondary forces and couples, and these could only be accepted as correct providing all the data with reference to masses and distances were included. Eight engines have been built, four having three working cylinders and four having four working cylinders, all embodying the crank arrangement described. They all ran with a complete absence of vibration, which supports the statement regarding the primary and secondary balance.

With reference to Mr. MacGibbon's remarks, it cannot be said that it is advisable to cool a two-stroke engine more quickly than any other type. For engines of normal design we have very little control over the rate at which the cylinders can be cooled. For efficiency reasons, it is better to cool an engine as little as possible, and only sufficiently to ensure the proper working and lubrication of the liner. The statement that less heat is rejected to the cooling system in a two-stroke engine than in a four-stroke one, is based on actual tests carried out by the Fiat Co. Although the working m.i.p. adopted for two-stroke engines is generally less than for four-stroke engines, this does not mean that the former cannot equal the latter, nor is it due to any difficulty in cooling. The question is largely bound up in the general loading of all the heat- and

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mechanically-stressed materials. The rating commonly employed has been found, from long experience, to be the best from all points of view.

I agree with Mr. Love's statement that supercharging has given the four-stroke engine a new lease of life, because attention has recently been devoted to this subject with a view to placing the four-stroke engine on a more competitive basis. I think it is generally accepted that the advantages to be derived from supercharging can be obtained equally well with two-stroke engines, and, as a matter of fact, probably the earliest experiments on supercharging were made with the latter engine. As far back as 1910 two-stroke Diesel engines were running with mean pressures more than 50 per cent. in excess of the normal, or just as much as can now be obtained from the four-stroke engine. It is well known that bearings subject to reversing loads are easier to lubricate than those sustaining loads of constant direction. The problem of lubricating the four-stroke engine would, therefore, appear to be easier than in the two-stroke engine, but in view of the fact that so many two-stroke engines are running satisfactorily with quite normal oil pressures, it may be said that this aspect of the subject is not now of serious importance. In any case, the double-acting two-stroke engine will possess this advantage. The disadvantage of a machine having reversing loads is that it is apt to become noisy when wear takes place.

The four-stroke cylinder liner is undoubtedly a simple casting, and Mr. Love is correct in his inference that in the two-stroke engine the complication has been transferred from the cylinder head to the cylinder liner. The vital difference, however, lies in the fact that the complication has been transferred from the part of the machine where both temperature and pressure stresses are very high, to a part where they are practically non-existent. The simplification has been brought about in the components, which have always given the most trouble. Actual experience has shown that the two sides of the liner in way of the ports have given no trouble, although they may be at considerably different temperatures. Circulation of the

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Mr. D. M. Shannon.

water through the exhaust-port bars is bound to be more active than through the inlet-port bars, and this to some extent may prevent any unequal expansions which might be considered of a serious nature.

The Fiat Co. have never had much trouble in obtaining overloads of from 40 to 50 per cent. It is, of course, accomplished at slightly higher revolutions according to the propeller law. Unfortunately, I am not in a position to give any data on the relative number of two- and four-stroke engines now being built for the Italian Navy. The statement in the paper that twelve engines of a certain type had been built for naval purposes was certainly not intended to infer that the Fiat engine was the only one being fitted in Italian warships.

I regret that it is not possible to answer Mr. Brown fully, as political reasons prevent the publication of full details on the performance of the double-acting engine running in Turin. The only general statement which can be made is that its performance is quite as good as any other engine of similar type and dimensions. The piston rods have not given any trouble, and the combustion spaces are much about the same as those for the single-acting type, the only difference being that in the case of the lower side of the piston the experiments have been limited to four fuel valves only. For engines of moderate power, two fuel valves would be sufficient.

It is a fact that many of the earlier solid-forged crankshafts on oil engines of all types failed because they were designed according to rules that gave too small dimensions. Since these errors have been corrected, it is safe to state that the solid shaft is giving just as satisfactory a performance as the built-up shaft. The revolutions for the performance curves shown in Fig. 28a were 100 per minute, and I regret that this was omitted from the diagram. I confirm that the horse-power is that in use in this country, and not the smaller Continental one.

I can only repeat what I have said in my answer to Mr. MacGibbon, that tests made by the Fiat Co. support the statements given with reference to the heat flow. It should not

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be overlooked that for cylinders of equal power the two-stroke engine will be considerably smaller, and it is conceivable without further argument that the heat rejected may be less in the case of the smaller cylinder. For cylinders of equal dimensions, Mr. Brown's figures are probably quite in order.

Mr. Bruce has made some valuable remarks on the design of large heavy-oil engines, and I am glad that they more or less correspond with the Fiat Co.'s practice. The method of securing the main-bearing caps by means of through bolts, which at the same time take the whole of the gas pressure stresses, is not a sound one, for the reasons given by Mr. Bruce. The economic limit of the oil engine is undoubtedly a dimensional one, and as two-stroke engines can develop at least 60 per cent. more power than four-stroke engines of the same cylinder capacity, it is natural that the latter will be the first to call a halt. The compromise adopted by four-stroke designers, in order to increase the power on the propeller shaft, is to detach scavenging pumps, air compressors, and circulating pumps, and drive them separately, a practice which rather complicates any engine-room layout. The question of the heat flow has already been dealt with in reply to other contributors.

In answer to Mr. Rettie, the Fiat Co. have equipped two Diesel-electric vessels, the results from which have fully demonstrated the utility of the engine for this special purpose. The first vessel has two engines, which are used in the normal way for supplying current to the single motor on the propeller shaft. In the second vessel, four engines, each of 1,000 b.h.p., are installed. Full details of these two vessels have been published in the technical press.

I cannot understand why Mr. Calderwood has inferred from the paragraph on page 622 that the majority of two-stroke engines on order at the present time are of the Fiat type. The figures which he puts forward on behalf of another engine are, therefore, quite unnecessary, and add nothing to the value of the discussion. The paragraph referred to is a general one, giving the position of the oil engine as a whole. I do not propose to discuss his figures, but can only say that the position

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enjoyed by the engine he mentions is almost entirely due to British engineers, and that the output of Fiat engines for last year was in excess of the one mentioned, so far as machinery constructed by the chief licensors is concerned. My statement on the value of the additional row of supercharging ports has been fully substantiated by the Fiat Co. experimentally, and independently by Nobel, as Mr. Calderwood will find out if he cares to refer to the paper* on the Nobel engine read before this Institution. Supercharging ports as fitted by some makers are inefficient. As a matter of fact, they are rather a nuisance, since the piston rings have to run over the edges of an extra row of ports, which does not tend to prolong their life. The large volume between the ports and the non-return valves is also a distinct disadvantage, since it gets filled up with high-pressure gases and has to be exhausted and scavenged, all of which means loss of power. Another disadvantage is that the non-return valves are under a higher pressure and for a longer period than is the case with the design adopted by the Fiat Co. There is, therefore, less likelihood of flame leaking into the scavenging-air system, and engines without the supercharging ports may be looked upon as safer.

So far as the lubrication of the piston skirts is concerned, I have given my own experience, having extensively experimented with engines in which the piston skirts dipped into the crank-chamber, and with engines having the pistons entirely external to the crank-chamber, such as the Fiat type. There is absolutely no question as to which type is superior, both for cleanliness and low consumption of lubricating oil. Fitting lantern rings of any design is not entirely satisfactory, and can only be considered a palliative and not a cure. Mr. Calderwood himself states that they do not prevent the lubricating oil becoming discoloured, and, despite any statements to the contrary, its lubricating value must be lowered. Forming a space between two lantern rings with a drain is not effective, as the carbonised oil is generally too thick to be drained away. I have always found glands of this type to act

* Trans. of the Institution, vol. lxix, p. 566.

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as traps for retaining the stuff that they were designed to remove. Unless it can be drained away properly, the dirt is only carried back to the cylinders, causing serious liner wear, a fact well known to Mr. Calderwood.

It is difficult to know how the speed of 200 r.p.m. has been arrived at as the point at which it becomes necessary to fit piston-rod glands. It is not only the oil splashed about that matters, but it should not be overlooked that the pistons are working in an oily atmosphere which is always present, irrespective of the revolutions. This has given rise to the application of crank-chamber air circulators, which have been fitted to engines of the type mentioned by Mr. Calderwood, and which are claimed to have effected a very large saving in lubricating oil. If these facts are admitted, they only support my contention of the comparative inefficiency of wipers and lantern rings, since, obviously, the oil now recovered must have been lost by way of the piston skirts and exhaust ports. The direct method of preventing the oil reaching the pistons is the only correct solution. With copious forced lubrication, it is impossible to prevent oil being splashed on to the pistons, even in the case of large slow-speed engines. It can be taken as definite and without any academic qualifications that, where head-room is available, there is no construction from the point of view of overhauling, lubrication, and reduced liner wear, as good as that in which the pistons are kept entirely out of the crank-chamber, a practice which is now being adopted on many of the engines of the make so freely mentioned by Mr. Calderwood.

Fig. 26 serves the useful purpose of pointing out the simplicity of the combustion chamber, which is all that it was intended to do, and if Mr. Calderwood will refer to the other sections of Fiat engines he will easily understand that there was no attempt, covert or otherwise, to mislead anyone. In a paper such as this it is quite unnecessary to point out self-evident elementary facts. Whatever Mr. Calderwood's opinions on the shape of the Fiat cover are, they cannot detract from the fact that not a single failure has been recorded, a perfor-

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mance which has not been equalled by the other two designs of cover shown in Fig. 26.

Perhaps the use of the word "absolute" in connection with the overload tests was unfortunate, but the fact remains that so far as any published data go, the Fiat overload test is the most severe applied to any oil engine. The figures quoted by Mr Calderwood for mean pressures are just ordinary, as I myself have designed and run two-stroke engines with mean pressures far in excess of anything that could be accomplished by engines having an additional row of supercharging ports. Mr Calderwood is definitely misleading in suggesting that 110 lbs. per square inch is the maximum indicated-pressure obtainable by an engine of the Fiat type, and the suggestion is probably made with a view to justifying the method of supercharging adopted on another engine, the commercial rating of which would be just the same if the supercharging ports were omitted altogether, a fact which conclusively proves that there is no virtue in fitting them.

I attach great importance to the manner in which through bolts are fitted. A Diesel engine frame may be treated as an elastic structure, and it is essential that all these bolts be tightened up to the same degree to prevent vibration and other phenomena when the working load is applied. The usual practice is to calculate the strain for the maximum piston load. The nut on the bolt is then screwed down tight enough to remove all play, and is afterwards turned through a definite angle to stretch the bolts to the calculated amount. This method does not, however, take into account the compressibility of the framing or any variations in the material of the different bolts. A more exact method is to make the top-end screwed portions of the bolts longer than that necessary for the holding-down nut. After the nut is screwed down an annular hydraulic piston is secured to the projecting part of the bolt, the water cylinder resting on the top of the framing. The annular portion is then loaded with a definite hydraulic pressure, and the nut tightened down in the usual way. This method eliminates the effect of all the variables mentioned.

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THE BALANCE OF INTERNAL-COMBUSTION ENGINES.

By Prof. WILLIAM KERR, Ph.D., A.R.T.C.,
Associate Member of the Institution.

3rd April, 1928.

AN inspection of the Proceedings of the Institution for many years back would convey a very clear impression of the intensity of thought and effort expended on the development of the internal-combustion engine, especially of the high-power type. The examination would show how thoroughly attention has been directed to those difficulties of operation and construction that constitute the main problems, to the seeming neglect of the matters involved in what may be termed the dynamical aspects of the system. These are, no doubt, of secondary moment; but while the establishment of type requires an absolute and sustained concentration on the main issues, the secondary questions and the finer points arise as a consequence of success; and the perfection of type demands their ultimate and laborious consideration.

The internal-combustion engine has achieved an undoubted triumph, but the inevitable consequences of final success and rapid progressive development display themselves. It will be admitted that the outstanding questions in this line at the moment centre on the phenomena of vibration. The subject obtrudes itself in many ways. In the main, the troubles due to torsional oscillations have been primarily responsible for the active review of the dynamical features of the drive that characterises a good deal of current discussion and investigation; but other important issues are also involved, and the subject may be expected to develop in various directions,

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The torsional vibration problem is one of a critical state creating insecurity of structure. It is a dangerous condition; but other kinds of vibration are possible that are mainly objectionable in character without being equally catastrophic in effect. But whether seriously dangerous or simply disturbing, any proper discussion of any such occurrences must require the examination of those characteristic irregularities of engine action in which they find their origin. These irregularities are the unbalanced effects in the engine; and it is my simple purpose herein to present them in general outline with a view to emphasising that they are, on the whole, capable of definite, and fairly ready, assessment as to magnitude and order.

Their consequences are not so, however. The theoretical problem of out-of-balance effects is the same in all engines of the same type, irrespective of size; but the practical problem varies widely. Even for similarity in size the nature of the application may change the question. A four-cylinder petrol engine may be a sound proposition for a car and inapplicable to an aeroplane; a four-stroke four-cylinder arrangement may be a good high-speed proposal for light powers or auxiliary purposes where a six-cylinder arrangement would create difficulties; or a two-stroke six-cylinder engine may demonstrate superiority over a four-cylinder one for main line drives in other respects than maximum power capacity. It is not only the magnitude of the disturbances inherent in the engine action that is important; but the order of these and their due relation to constructional rigidity and structural support also require attention.

In these ultimate questions experience alone can, in general, decide. But this judgment must utilise the facts that can be established. It is only the proper combination of quantitative estimate and experience of effects that leads to accurate and satisfactory judgment. Without the former, the latter is haphazard in its decisions; without the latter, the former is purely academic in its conclusions; and the neglect of a proper correlation of the two leaves the power and process of search

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in the control of those rather vague notions that are not inconspicuously displayed in this subject.

Modern conditions of running are such that it is hardly possible to escape resonant ranges altogether. But when are they immediately dangerous, likely to prove ultimately serious, or merely objectionable in their mode of disclosure? What kind of effect has produced them, what is its magnitude, what minimum value is permissible, and how may it be reduced? A minute high order frame force in a high-speed petrol engine may, by resonance, lead to the fracture of a pane of glass in a car; one torque order of quite appreciable range of fluctuation in an engine system may act in the critical torsional zone without undue danger, when another of larger, but still commensurable, magnitude produces a serious situation. Why? A ship's hull may undergo vertical vibration under the influence of the engine effects; are they produced by frame forces or frame couples, and are both equally effective in this way?

Such questions are numerous, but answers can only be definite when the observation of effects has been allied with the estimation of causes. Further, when a cure of any kind is to be attempted by some process of "balancing," it is necessary to examine the consequences in other directions. Balance methods, beyond the choice of self-balanced systems, generally involve mass additions of some kind, either to the rods, or the cranks, or by the introduction of special geared masses. In so far as these lead to the cancellation of undesirable forces they are advantageous; but they will also increase angular inertia effects, and so augment the possibilities of torsional and other difficulties. But there is certainly scope for the examination of the question as to how far the addition of masses may be carried in any case with a margin of benefit to the effect considered.

At every stage of the subject the need for quantitative calculation arises, and the discussion that follows is wholly concerned with this. It attempts a unification of ideas and methods in connection with the important actions in the characteristic systems of internal-combustion engines.

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The Single Line Effects.

The Individual Forces. In a single line of engine parts, driven by fluid pressure through a connecting-rod and crank mechanism, there are two systems of forces of main importance—the frame and shaft systems. The several forces comprising these are as diagrammatically indicated in Fig. 1;

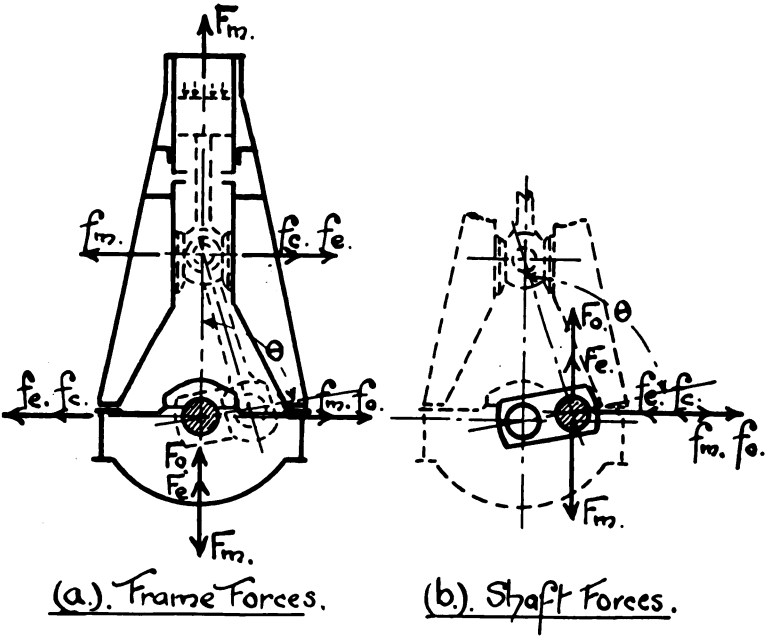

Fig. 1.

and the resultant effects may clearly be classified as frame and shaft forces, and frame and shaft torques.

The individual forces are due either to fluid forces or to inertia. The modes of action of the former are obvious. The establishment of the latter, however, requires a certain reduction and concentration of the distributed masses of the moving parts. This is customarily effected by taking so-called "equivalent masses" at the crosshead and crank pins, which procedure is naturally correct for the actual reciprocating and

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rotating masses, but is only partially so for the connecting rod. The usual division of the rod weight between the pins deals quite properly with the problem of the linear motion of the rod, but is erroneous for the treatment of angular inertia. It is, however, desirable to retain the simplicity of this division; and, in order to rectify the error, a "correction couple" may be introduced.

If the total weight of the rod is w, and its radius of gyration

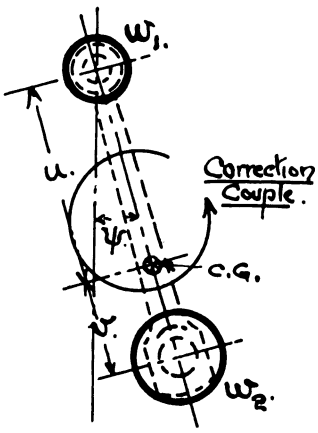

Fig. 2.—Connecting Rod Reduction.

—about the C.G.—is k, the usual concentrations, w_1 at the crosshead and w_2 at the crank, are—referring to Fig. 2—

$$w_1 = w \cdot \frac{v}{u+v}; \quad w_2 = w \cdot \frac{u}{u+v},$$

and the moment of inertia about the C.G. is then, apparently, $w \cdot u \cdot v/g$, in place of the correct value $w \cdot k^2/g$. Hence, for any angular acceleration, $\ddot{\psi}$, of the rod, the accelerating torque is wrongly assessed, and it is necessary to include, as a correction for the error, the couple

$$\frac{w}{g}(k^2 - u \cdot v)\ddot{\psi} \quad - \quad - \quad - \quad (1)$$

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as indicated in Fig. 2. The rod is then adequately treated by means of the masses w_1 and w_2, and this correction couple.

By reference to Fig. 1, the separate forces arising in the single line of parts may be briefly described as follows:—

F_m represents the motive force due to fluid pressure. It acts in opposite directions on cylinder and bearings, and is, therefore, balanced so far as the frame is concerned; but it

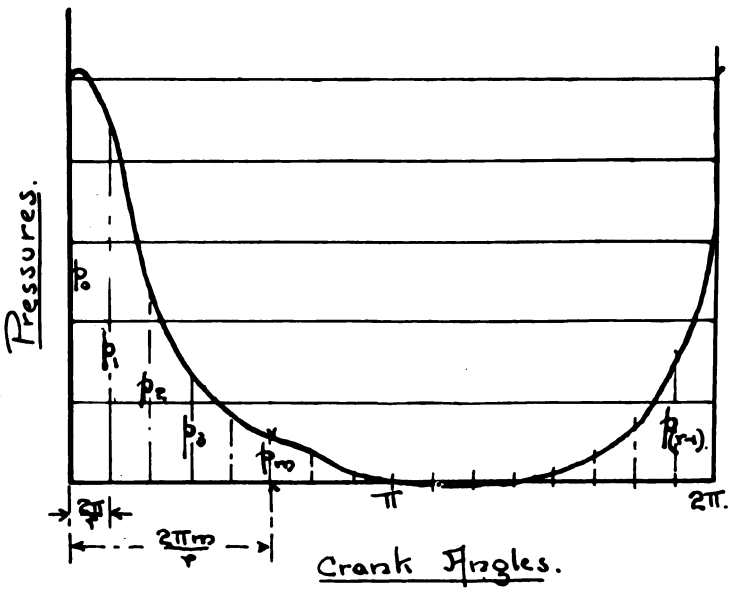

Fig 3.—Indicator Card and Angle Base.

is obviously an important shaft force. The corresponding transverse force f_m—due to the obliquity of the rod—acts in opposite directions on bearings and guides, so producing a frame torque. It also acts on the shaft, as shown.

The inertia force of the total reciprocating mass is indicated by F_e. For the crank position given, it is upwards on the shaft and frame; and it constitutes a highly important item in the frame system. The transverse effects of this force are shown by the arrows marked f_e on the frame—creating torque —and the similar f_e indicated on the shaft.

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The centrifugal force of the rotating mass is defined by its vertical and horizontal components, respectively F_o and f_o. Both act on the shaft and frame. It is, of course, only in so far as the rotating masses are unbalanced that they contribute to the centrifugal force in question.

The correction couple, already referred to as necessary for the accurate inclusion of the rod effects, necessitates the introduction of the forces, f_c, marked on the shaft and frame diagrams.

The forces that have been separately mentioned comprise the entire set in the engine unit, and each can be concisely expressed in series form.

The motive force F_m is obtainable from the indicator card—assumed or actual—laid down on a crank-angle base, as illustrated in Fig. 3. For the present it may be taken that a two-stroke cycle is followed, as the equality of the cyclic and rotational periods then makes the process of recording the cyclic fluid forces in terms of the crank angle at once direct and natural.

The problem of expressing this force in series form is merely one of determining the Fourier coefficients for the pressure curve. The relation would be

$$F_m = A\left\{\begin{matrix} B_o' + B_1'\cos\theta + B_2'\cos 2\theta + \cdots B_n'\cos n\theta + \cdots \\ + C_1'\sin\theta + \quad - \quad - \quad - \quad - \quad - \quad C_n'\sin n\theta. \end{matrix}\right\} \quad \cdot \quad (2)$$

in which A represents the piston area, so that the coefficients B′ and C′ are pressures.

If the curve of pressure, arranged on an angle base, is divided into r equal parts, the ordinates at the equal intervals being p_o, $p_1 \cdots p_m \cdots p_{(r-1)}$, where p_m represents the general ordinate, then the coefficients in (2) are given by the well-known rules:—

$$\left.\begin{aligned} B_o' &= \frac{1}{r}\sum_{m=o}^{m=(r-1)} p. \\ B_n' &= \frac{2}{r}\sum_{o}^{(r-1)} p_m \cos n\,\frac{2\pi m}{r}. \\ C_n' &= \frac{2}{r}\sum p_m \sin n\,\frac{2\pi m}{r}. \end{aligned}\right\} \quad \cdot \quad \cdot \quad (3)$$

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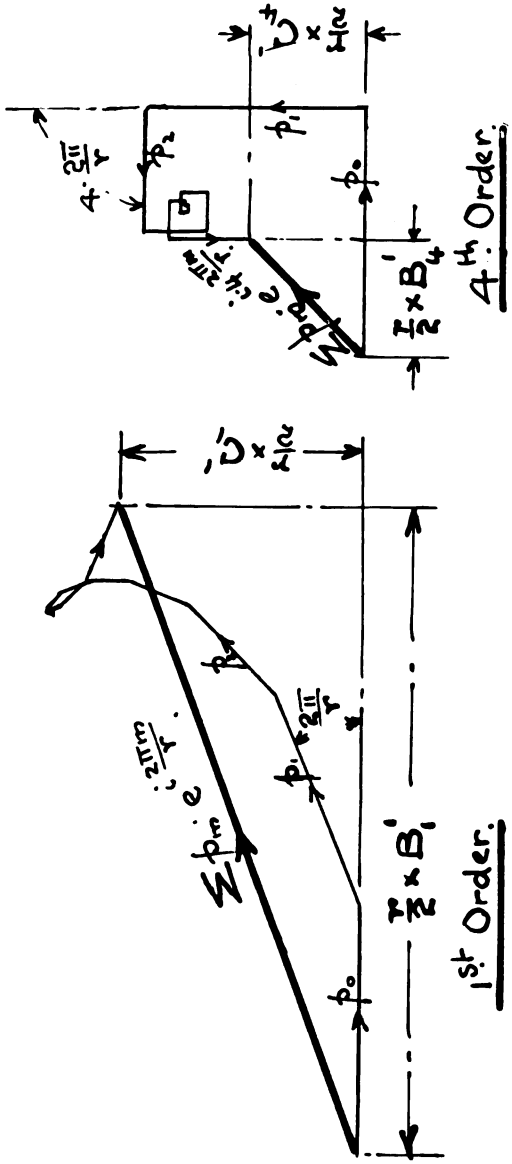

Fig. 4.—Vector Summations for Fourier Coefficients.

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From these relations, with n taking successively the values 1, 2, ---, each coefficient may be directly—if somewhat laboriously—computed. The vector method of working, derived from these relations, is, however, of interest, and of special value in connection with the present subject. If the coefficients of the same order are added as perpendicular vectors, there is obtained

$$B_n' + iC_n' = \frac{2}{r} \sum_{0}^{(r-1)} p_m e^{in\frac{2\pi m}{r}} \quad - \quad - \quad - \quad (4)$$

in which the index of e merely defines the angle at which p_m has to be set off as a vector. The symbol i is only a special method of writing $e^{i\pi/2}$, and, therefore, represents a unit vector drawn at right angles to the standard reference direction. The interpretation of (4) is then, simply, that B_n' and C_n' are the perpendicular components of the resultant of the vector addition of the successive p ordinates of the curve, summed together in vector polygon fashion with the exterior angle of the polygon given by $2\pi n/r$. In this way the coefficients of the cos and sin terms of the same order are obtained from one diagram. Fig. 5 shows, as an illustration, the developments for the first and fourth order coefficients of the pressure curve given in Fig. 4.

This graphical method of evaluation may not be quite so accurate as direct calculation; but for practical purposes, and in view of the approximate nature of the card in many cases, it is probably sufficiently so for the more important harmonic orders of the curve.

The expression for B_o' in (3) above shows that it is merely the average height of the curve, and this could be obtained by planimeter or otherwise. B_o' may also include the weight of the moving parts if it be desired to embody these in the treatment of the shaft loads. In that case, of course, it is the weight per unit piston area that has to be incorporated in the given coefficient.

If the total reciprocating weight is W_1, then the inertia force of this is given—for the engine without "offset"—by the expression

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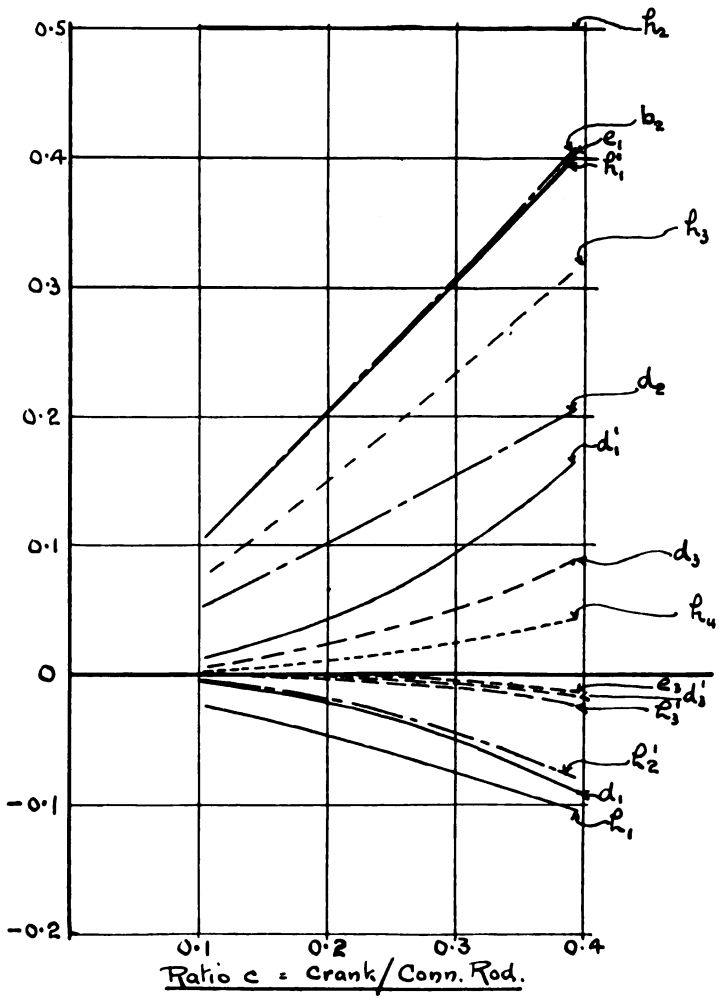

Fig. 5.—Functions of Crank-Connecting-Rod Ratio.

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$$F_c = \frac{W_1}{g}\omega^2 r\left\{\cos\theta + b_2'\cos 2\theta + b_4'\cos 4\theta + \cdots\right\} \quad (5)$$

wherein ω is the angular velocity of the crank (radians per sec.) and r is the crank radius (ft.) The coefficients b' are functions of the crank-connecting-rod ratio, c, and the values of those of any practical significance are obtainable from the graphs in Fig. 5.

The vertical component, F_o, of the centrifugal force of the rotating weight W_2 is simply

$$F_o = \frac{W_2}{g}\omega^2 r\cos\theta = \frac{W_1}{g}\omega^2 r\left(\frac{W_2}{W_1}\cos\theta\right) \quad (6)$$

and this may obviously be incorporated in the first term of (5) if desired.

The horizontal component of the centrifugal force is

$$f_o = \frac{W_1}{g}\omega^2 r\left(\frac{W_2}{W_1}\sin\theta\right) \quad (7)$$

The horizontal or transverse force, f_m, due to the gas pressure, may be written

$$f_m = A\{D_o' + D_1'\cos\theta + D_2'\cos 2\theta + \cdots - E_1'\sin\theta + E_2'\sin 2\theta + \cdots\} \quad (8)$$

The coefficients for this could be determined from a curve easily derived from the piston pressures at different crank angles; or, alternatively, they may be calculated from the following relations which are established by analysis. The factors e_1 and e_3, which appear in these statements, are functions of the ratio c, and are plotted in Fig. 5.

$$\begin{aligned}
D_0' &= \tfrac{1}{2}(e_1 . C_1' + e_3 . C_3') \\
D_1' &= -\tfrac{1}{2}e_1(C_0' - C_2') + \tfrac{1}{2}e_3(C_2' + C_4') \\
D_2' &= -\tfrac{1}{2}e_1(C_1' - C_3') + \tfrac{1}{2}e_3(C_1' + C_5') \\
D_3' &= -\tfrac{1}{2}e_1(C_2' - C_4') + \tfrac{1}{2}e_3(C_0' + C_6') \\
D_4' &= -\tfrac{1}{2}e_1(C_3' - C_5') - \tfrac{1}{2}e_3(C_1' + C_7') \\
E_1' &= \tfrac{1}{2}e_1(2B_0' - B_2') + \tfrac{1}{2}e_3(B_2' - B_4') \\
E_2' &= \tfrac{1}{2}e_1(B_1' - B_3') + \tfrac{1}{2}e_3(B_1' - B_5') \\
E_3' &= \tfrac{1}{2}e_1(B_2' - B_4') + \tfrac{1}{2}e_3(2B_0' - B_6') \\
E_4' &= \tfrac{1}{2}e_1(B_3' - B_5') + \tfrac{1}{2}e_3(B_1' - B_7')
\end{aligned}$$

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The transverse forces, f_e, due to the reciprocating parts are expressed by

$$f_e = \frac{W_1}{g}\omega^2 r\left\{d_1 \sin\theta + d_2 \sin 2\theta + d_3 \sin 3\theta + \cdots\right\} \quad (9)$$

and the coefficients, $d_1 \cdots$, are given graphically in the curves of functions of c.

The correction couple for the rod is determined from (1) by means of the expression for the angular acceleration $\ddot{\psi}$. The value of the forces, f_c, due to this couple may then be deduced as

$$f_c = \frac{W_1}{g}\omega^2 r\left\{\frac{w}{W_1}\left(\frac{uv - k^2}{r_2}\right)\right\}\left\{d_1' \sin\theta + d_3' \sin 3\theta + \cdots\right\} \quad (10)$$

in which w, u, v, and k are as previously defined—see equation (1)—and the d' coefficients are functions of the c ratio, given in Fig. 5.

All the forces in the simple engine arrangement have now been outlined in sufficient detail to illustrate how the coefficient of any chosen term of any one force may be determined. It remains to show how the various actions are grouped together to express the characteristic frame and shaft effects.

Frame and Shaft Effects. The total unbalanced force on the frame in the line of reciprocation is composed of the inertia force of the reciprocating parts, F_e, and the vertical component of the centrifugal force, F_o. It is seen from (5) and (6) that this sum is

$$(F_e + F_o) = \frac{W_1}{g}\omega^2 r\left\{\left(1 + \frac{W_2}{W_1}\right)\cos\theta + b_2' \cos 2\theta + \cdots\right\}$$

and this may simply be stated as

$$\text{Line frame force} = F = (F_e + F_o) = \Sigma b_n \cos n\theta \quad (11)$$

wherein

$$b_1 = \frac{W_1}{g}\omega^2 r \cdot \left(1 + \frac{W_2}{W_1}\right)$$

$$b_2 = \frac{W_1}{g}\omega^2 r \cdot b_2'.$$

— — —

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The only unbalanced frame force transverse to the line of motion is f_o—the simple single order quantity already given by

$$\text{Transverse frame force} = f_o = \frac{W_1}{g}\omega^2 r\left(\frac{W_2}{W_1}\sin\theta\right) \qquad (7)$$

The remaining frame forces are present in pairs, and produce a couple—the frame torque or "torque reaction." Reference to Fig. 1 will show that this is given by

$$(f_m - f_o - f_c)y.$$

The length y can be developed in terms of θ, and the torque then becomes the series

$$Ar\left[P_o + \Sigma(P_n' \cos n\theta + Q_n' \sin n\theta)\right]$$
$$-\frac{W_1}{g}\omega^2 r^2\left[\left\{\Sigma h_n \sin n\theta\right\} + \frac{w}{W_1}\left(\frac{uv - k^2}{r^2}\right)\Sigma h_n' \sin n\theta\right] \qquad (12)$$

in which the P' and Q' coefficients are derived from the series for motive forces by means of the relations.

$$\begin{aligned}
P_0' &= \tfrac{1}{2}(D_1' + C_1') \\
P_1' &= \tfrac{1}{2}C_2' + D_0' + \tfrac{1}{2}D_2' \\
P_2' &= -\tfrac{1}{2}(C_1' - C_3') + \tfrac{1}{2}(D_1' + D_3') \\
P_3' &= -\tfrac{1}{2}(C_2' - C_4') + \tfrac{1}{2}(D_2' + D_4') \\
&\text{— — — — — —} \\
Q_1' &= \tfrac{1}{2}E_2' + B_0' - \tfrac{1}{2}B_1' \\
Q_2' &= \tfrac{1}{2}(B_1' - B_3') + \tfrac{1}{2}(E_1' + E_3') \\
Q_3' &= \tfrac{1}{2}(B_2' - B_4') + \tfrac{1}{2}(E_2' + E_4') \\
&\text{— — — — — —}
\end{aligned}$$

The h and h' coefficients are merely functions of the crank-connecting-rod ratio, and are given—in so far as they are of any importance—by the graphs in Fig. 5. In general, the inertia terms, in all calculations of the kind under review, are insignificant beyond the third or fourth order, a fact which explains the limited number of orders included in the graphed scheme.

It is clear that the expression in (12) may be stated in more

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concise fashion by combining the coefficients of corresponding terms, and writing

$$\text{Frame torque} = \overline{K} = \Sigma(l_n \cos n\theta + m_n \sin n\theta) \quad - \quad (13)$$

The grouped coefficients are easily obtained from the full expression in (12), or may be readily arrived at by following the scheme tabulated below, in which the general factors entered in the first row are multiplied by the corresponding coefficients in the other rows, the products for any order being algebraically summed to give the overall l and m values.

COEFFICIENTS FOR FRAME TORQUE.

	Zero Order.	1st Order.		2nd Order.		3rd Order.	
		Cos.	Sin.	Cos.	Sin.	Cos.	Sin.
$Ar.\times$	P_0'	P_1'	Q_1'	P_2'	Q_2'	P_3'	Q_3'
$\frac{W_1}{g}\omega^2 r^2\times$	—	—	h_1	—	h_2	—	h_3
$\frac{W_1}{g}\omega^2 r^2 \frac{w}{W_1}\left(\frac{uv-k^2}{r^2}\right)\times$	—	—	h_1'	—	h_2'	—	h_3'
Sums of Products =	l_0	l_1	m_1	l_2	m_2	l_3	m_3

In this way it is merely a simple arithmetical process to derive the coefficients of any order of the frame torque.

The shaft torque is very similar to the frame torque, the only difference between them being due to the correction couple for the rod. By reference to Fig. 1 (b), it can be seen that this shaft torque is directly given by

$$(F_m - F_e - F_o)r \sin\theta + (f_m + f_o - f_e - f_c)r \cos\theta,$$

but it may be shown that this is the same as (12), except that the odd sin orders in the third term of that expression are absent. Hence

$$\text{Shaft torque} = \overline{T} = \Sigma(l_n \cos n\theta + m'_n \sin n\theta) \quad - \quad (14)$$

wherein the l coefficients remain as before, and the m

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coefficients are slightly modified, the grouping being as shown in the following schedule:—

COEFFICIENTS FOR SHAFT TORQUE.

	Zero Order.	1st Order.		2nd Order.		3rd Order.	
		Cos.	Sin.	Cos.	Sin.	Cos.	Sin.
$Ar.\times$	P_0'	P_1'	Q_1'	P_2'	Q_2'	P_3'	Q_3'
$\frac{W_1}{g}\omega^2 r^2\times$	—	—	h_1	—	h_2	—	h_3
$\frac{W_1}{g}\omega^2 r^3 \frac{w}{W_1}\left(\frac{uv-k^2}{r^2}\right)\times$	—	—	—	—	h_2'	—	—
Sums of Products =	l_0	l_1	m_1'	l_2	m_2'	l_3	m_3'

The shaft and frame torques are respectively driving and reaction torques, and on an absolute basis must be recognised as having opposite signs. It is easy, however, to affix the appropriate sign if necessary.

The total shaft force is of a more complex nature than the effects already considered. As indicated in Fig. 1 (b), it is composed of two component sets of forces at right angles, and hence must be written as

$$-(F_m - F_e - F_o) + i(f_m + f_o - f_e - f_c)$$

where i denotes that the second system is perpendicular to the first. The signs appearing in this expression merely establish the convention that upward vertical forces and right-hand horizontal forces are to be considered positive. The various forces have already been considered separately, and on reference to the different expressions it will be clear that the summation may be briefly expressed by

$$\text{Shaft force} = \overline{P} = \{\Sigma(B_n \cos n\theta + C_n \sin n\theta)\} + i\{\Sigma(D_n \cos n\theta + E_n \sin n\theta)\} \quad (15)$$

and equations (2) to (10) will show on examination that the coefficients in (15) can be built up from the schedules below.

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COEFFICIENTS FOR VERTICAL SHAFT FORCE COMPONENT.

	Zero Order.	1st Order.		2nd Order.		3rd Order.	
		Cos.	Sin.	Cos.	Sin.	Cos.	Sin.
$(-A)\times$	B_0'	B_1'	C_1'	B_2'	C_2'	B_3'	C_3'
$\frac{W_1}{g}\omega^2 r+$	—	b_1	—	b_2	—	—	—
Sums of Products =	B_0	B_1	C_1	B_2	C_2	B_3	C_3

COEFFICIENTS FOR HORIZONTAL SHAFT FORCE COMPONENT.

	Zero Order.	1st Order.		2nd Order.		3rd Order.	
		Cos.	Sin.	Cos.	Sin.	Cos.	Sin.
$A\times$	D_0'	D_1'	E_1'	D_2'	E_2'	D_3'	E_3'
$\frac{W_1}{g}\omega^2 r\times$	—	—	$-\left(d_1-\frac{W_2}{W_1}\right)$	—	$-d_2$	—	$-d_3$
$\frac{W_1}{g}\omega^2 r\frac{w}{W_1}\left(\frac{uv-k^2}{r^2}\right)\times$	—	—	$-d_1'$	—	—	—	$-d_3'$
Sums of Products =	D_0	D_1	E_1	D_2	E_2	D_3	E_3

It will be clear that the shaft force summation, as it has been developed, can only be necessary for the examination of transverse shaft actions, since the driving effect of the forces is fully represented by the shaft torque expression. It is particularly in connection with this total shaft force that the method of dealing in detail with the separate forces in the system is advantageous.

The outline that has been given of the frame and shaft effects in a single engine line is wholly for the purpose of placing a variety of different actions on similar and consistent bases. It is the scheme of development and the procedure of using combined Fourier coefficients for any total effect that are important. Within the purpose of this paper the detail coefficients for separate actions are mainly illustrative, and for

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this reason the simple case of the cylinder and shaft in line has been adhered to throughout, and the influence of offset excluded. The appropriate coefficients for this special condition may, for the main effects, be found elsewhere, and they can then be introduced into the corresponding schemes in place of those given. The existence of offset only really affects the inertia terms, since the motive forces have to be dealt with by harmonic analysis from the cards, and will thereby be correctly interpreted for the offset allowed. The various inertia series are, however, rather more general than those for the simpler line arrangement, and the coefficients are somewhat altered. Nevertheless, the results for the straight line system give a reasonable approximation in practical cases of offset, and a relatively simple correction on the lower inertia orders of any effect is all that is really necessary for the attainment of considerable accuracy.

Two- and Four-Stroke Cycles. Throughout the previous work the assumption of two-stroke cycle action has been made, and this renders the simultaneous development of the motive and inertia forces in terms of integral multiples of the crank angle straightforward and rational. In the case of the four-stroke cycle, however, the cyclic pressure curve would naturally be based on two revolutions of the crank, and, therefore, apparently necessitates the employment of "half-crank orders." But the full cyclic process corresponds to one camshaft revolution, and it is preferable, for the purposes of general discussion, to base the four-stroke actions on "camshaft angles," and so retain the merits of the general methods employing integral multiples of the angle variable.

By the adoption of such a procedure it would only be necessary to express the motive forces in terms of ϕ, the camshaft angle, instead of θ, the crankshaft angle, and, since the general relationship

$$\theta = 2\phi$$

always holds, the inertia term coefficients already given would remain unaltered in value, but would now group with the

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double order coefficients of the "camshaft" series. The only change then necessary in the treatment is to write ϕ in place of θ in the general equations for the total effects, and, in the process of determining combined coefficients, to move the inertia term of any order in θ along to the column marking the double order in ϕ. Thus, for example, h_2—which is an inertia coefficient—is used either in the second θ order for a two-stroke cycle, or in the fourth ϕ order for a four-stroke cycle. A fourth order camshaft value and a second order crank value are equivalent; and the ninth camshaft order is the $4\frac{1}{2}$ crank order; and so on.

The development of the motive forces in terms of the camshaft angles necessitates, for an equally adequate treatment of a similar range of effects in the two types, that the pressure curve for the four-stroke case should be analysed with twice the number of ordinates employed for the two-stroke. This does not necessarily imply that twice the number of orders have to be worked out, but only that twice the number of ordinates have to be used in the determination of the coefficients of corresponding orders.

The lateral force, f_m, due to gas pressure, requires slight modification in respect of relationships between its coefficients and those of the longitudinal force F_m, since these relationships entail the use of the factors c_1 and c_3—see equation (8) and its context—which are really associated with crank angles. This difficulty may be overcome by separately analysing the lateral force curve, or by substituting the following statements for those given at equation (8), the equation itself, of course, still applying—with ϕ for θ.

$$\left.\begin{aligned}
D_0' &= \tfrac{1}{2}(c_1C_2' + c_3C_6') \\
D_1' &= +\tfrac{1}{2}c_1(C_1' + C_3') + \tfrac{1}{2}c_3(C_5' + C_7') \\
D_2' &= -\tfrac{1}{2}c_1(C_0' - C_4') + \tfrac{1}{2}c_3(C_4' + C_8') \\
E_1' &= \tfrac{1}{2}c_1(B_1' - B_3') + \tfrac{1}{2}c_3(B_5' - B_7') \\
E_2' &= \tfrac{1}{2}c_1(2B_0' - B_4') + \tfrac{1}{2}c_3(B_4' - B_8')
\end{aligned}\right\} \quad \text{(16)}$$

Again, the torque effects due to motive forces necessitate

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altered relations for the determination of the P' and Q' coefficients—see equation (12)—since the crank angle enters into the torque. Hence, in establishing the values of P' and Q', for association with ϕ, the following should be employed in place of the relations stated at equation (12):—

$$\left.\begin{aligned}
P_0' &= \tfrac{1}{2}(C_2' + D_2') \\
P_1' &= \tfrac{1}{2}(C_1' + C_3') + \tfrac{1}{2}(D_1' + D_3') \\
P_2' &= \tfrac{1}{2}C_4' + D_0' + \tfrac{1}{2}D_4' \\
P_3' &= -\tfrac{1}{2}(C_1' - C_5') + \tfrac{1}{2}(D_1' + D_5') \\
\text{—} &\quad \text{—} \quad \text{—} \quad \text{—} \quad \text{—} \quad \text{—} \\
Q_1' &= \tfrac{1}{2}(B_1' - B_3') - \tfrac{1}{2}(E_1' - E_3') \\
Q_2' &= -\tfrac{1}{2}B_4' + B_0' + \tfrac{1}{2}E_4' \\
Q_3' &= \tfrac{1}{2}(B_1' - B_5') + \tfrac{1}{2}(E_1' + E_5') \\
\text{—} &\quad \text{—} \quad \text{—} \quad \text{—} \quad \text{—} \quad \text{—}
\end{aligned}\right\} \quad . \quad . \quad (17)$$

The special points mentioned as requiring slightly altered calculation are all concerned with the motive forces and their effects, and analogous changes would be necessary in any general method of dealing with the two cases. But with such points understood, and the characteristic shift of the inertia terms appreciated, the establishment of the summed coefficients of the ϕ orders is in direct correspondence, at all stages, with the processes for the simpler cases based upon θ. The advantages of this method of using camshaft angles in the four-stroke cycle only become clear in the treatment of multi-cylinder engines. But it may also be mentioned that the method provides a ready means of including mass or force effects associated with camshaft or valve actions, should it be desired to analyse the consequences of such effects.

The Engine Elements—The General Harmonic Order.

The last section presented the measures of the various effects in a simple engine arrangement. The section might have been included quite appropriately as an appendix, but it has been incorporated in the main line of development because of the desirability of clearly establishing the conditions that all the effects—however different in action and consequence—are similarly expressed, and that the factors that describe the

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intensity of action are readily built up by simple calculation. It is desired to emphasise the fact that any selected order of any specified action can be evaluated directly without essential reference to any other action or order.

Any internal-combustion engine of real importance—from the present standpoint—is usually a multiple arrangement of some elementary form. Different types have different elementary basis forms, but the multiplication of the chosen unit gives the complete engine. The simple system already considered represents undoubtedly the basis operation in all cases, but it is also the element of the commonest engine type —the cylinder in line engine. Other types—opposed piston, Vee engines, etc.—may employ the same fundamental operation, but somewhat more elaborate basis forms are required for adequate description. Since any action may be examined through the medium of the general harmonic order of that action; and since the complete engine is best studied by means of the unit formation, it follows naturally that some consideration is necessary of the general order in relation to the typical element. It is not proposed—and from considerations of length it is hardly possible—to include every type of engine, but a reasonably wide selection of the important types may be made on which the details of the last section have a direct bearing. Other cases—such as rotary frame engines—which would require the re-establishment of appropriate elementary series are ignored. It should be understood, however, that, given the harmonic coefficients for any case, the methods which follow are general.

Single Piston-Crank Arrangement. This is the case already dealt with, illustrated in Fig. 1, and discussed analytically by means of the equations previously given. It is the "typical element" of the ordinary cylinder in line engine.

Consider the line frame force of this unit again. The general term is—see equation (11)—

$$F_n = b_n \cdot \cos n\theta,$$

and merely represents a simple harmonic variation of force

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along the line of reciprocation. But, since the trigonometrical factor can be written

$$\text{Cos } n\theta = \tfrac{1}{2}(e^{in\theta} + e^{-in\theta}),$$

the nth order line frame force becomes

$$\bar{F}_n = \left(\frac{b_n}{2}\right)e^{in\theta} + \left(\frac{b_n}{2}\right)e^{-in\theta} = Fe^{in\theta} + Fe^{-in\theta} \quad \cdot \quad (18)$$

Now, since $e^{in\theta}$ is merely the algebraic notation for a vector set at the angle $n\theta$, and since θ is the angle swept out by the rotating crank in time t, *i.e.*, $\theta = \omega \cdot t$, it follows that this method of writing the frame force leads to an interpretation in terms of rotating vectors. The two vectors represented by the two terms in (18) rotate in opposite directions—the "forward" and "reverse" vectors—at n times the speed of the crank. They are of equal length, and their sum is the nth order frame force.

Thus the total force could be visualised as the vector sum of a complete series of forward and reverse "vector cranks," whose speeds correspond to the harmonic orders, and whose lengths represent the half values of the appropriate coefficients.

There is but little special merit in this process of thought in so simple a case as that of a single line force of this kind, but the conception is easily established therein, and it requires but little extension of the same idea to cover the most elaborate case.

If the frame torque is considered, the nth order, as given in equation (13), is

$$\bar{K} = l_n \cos n\theta + m_n \sin n\theta,$$

and since

$$\text{Cos } n\theta = \frac{1}{2}\left(e^{in\theta} + e^{-in\theta}\right); \text{ and } \sin n\theta = \frac{1}{2i}\left(e^{in\theta} - e^{-in\theta}\right)$$

there is obtained on substitution and reduction

$$\bar{K}_n = \left(\frac{l_n}{2} - i\frac{m_n}{2}\right)e^{in\theta} + \left(\frac{l_n}{2} + i\frac{m_n}{2}\right)e^{-in\theta}$$

Now, the symbol i stands for the so-called imaginary $\sqrt{-1}$, but from the vector point of view it is merely a special way

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of stating $e^{i\frac{\pi}{2}}$, and, therefore, it represents a unit vector set at 90 degrees to the standard reference direction. Hence the complex coefficients of $e^{in\theta}$ and $e^{-in\theta}$ are readily dealt with by summing the perpendicular vectors which they express, so obtaining the equal right-angled triangles shown in Fig. 6.

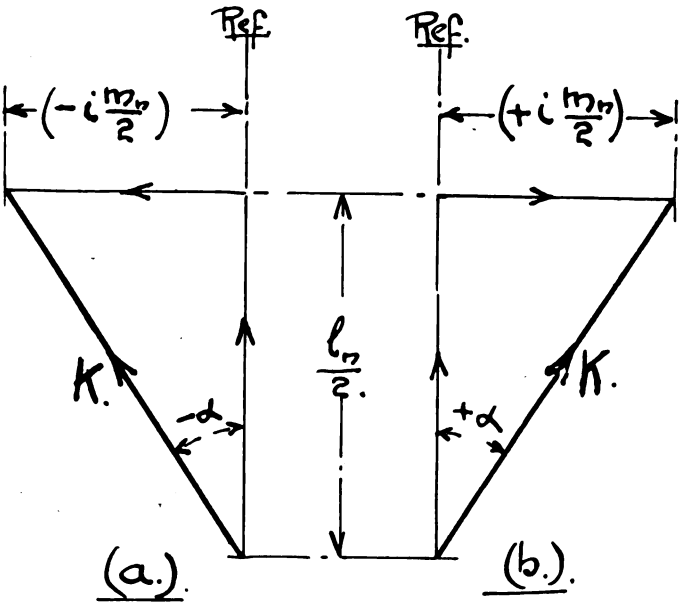

Fig. 6.

It is seen therefrom that the magnitude, K, of the sum is given by

$$K = \tfrac{1}{2}\sqrt{l_n^2 + m_n^2},$$

while in Fig. 6 (a) K is "behind" by angle α, and in Fig. 6 (b) it is "ahead" by the same value. This gives

$$K_n = (Ke^{-i\alpha})_n e^{in\theta} + (Ke^{i\alpha})_n e^{-in\theta} \quad \cdot \quad \cdot \quad (19)$$

This case then adds another feature to the form established by the simpler frame force. It has now to be recognised that the two vectors giving the nth order effect may have a phase

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"lag" or "lead" relation to the "forward and reverse nth speed cranks." It should be noticed that the quantities confined within brackets in (19) ought to be interpreted as a whole, the α value always remaining associated with K and expressing the phase relationship of the nth order vector K and the nth order "crank" $e^{\pm in\theta}$. The symbol α will always be used in

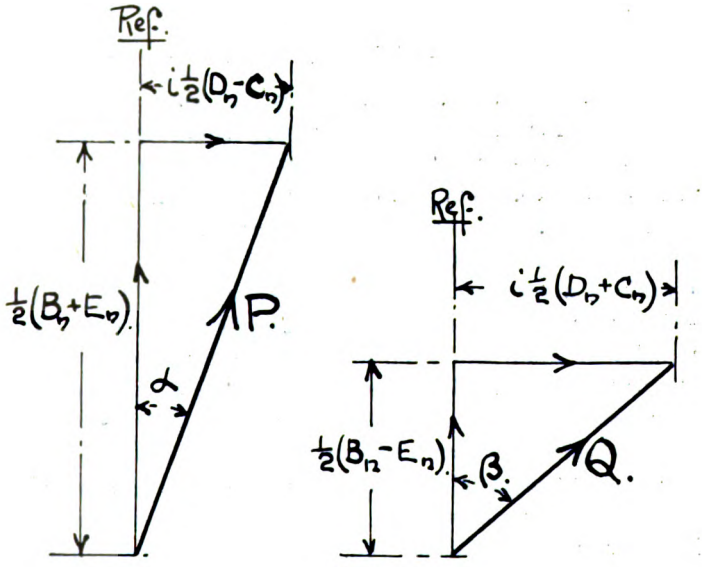

Fig. 7.

this sense, and may, of course, be similarly associated with other quantities.

The shaft torque so closely resembles the case just developed that it may at once be stated as

$$\overline{T}_n = (Te^{-i\alpha})_n e^{in\theta} + (Te^{i\alpha})_n e^{-in\theta} \quad - \quad - \quad (20)$$

the form and values being established by the process just outlined. It has to be understood, of course, that α has the same meaning, but not the same value, as before.

If the shaft force be now taken, equation (15) shows that

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$$\bar{P}_n = B_n \cdot \cos n\theta + C_n \cdot \sin n\theta + iD_n \cdot \cos n\theta + iE_n \cdot \sin n\theta,$$

which is really the sum of two mutually perpendicular nth order force effects. By the usual process of transformation this becomes

$$\bar{P}_n = \left\{\frac{B_n}{2} + \frac{E_n}{2} + i\left(\frac{D_n}{2} - \frac{C_n}{2}\right)\right\} e^{in\theta} + \left\{\frac{B_n}{2} - \frac{E_n}{2} + i\left(\frac{D_n}{2} + \frac{C_n}{2}\right)\right\} e^{-in\theta}$$

which, by means of Fig. 7, is easily seen to be

$$\bar{P}_n = (Pe^{i\alpha})_n e^{in\theta} + (Qe^{i\beta})_n e^{-in\theta} \quad \cdot \quad \cdot \quad \cdot \quad (21)$$

This case is interpreted in exactly the same way as before. The expression describes the nth order shaft force as the sum of two vectors—one P in length rotating with the "forward nth speed crank" but leading it by α, and one Q in length at β ahead of the "reverse nth speed crank."

The development of the shaft force in this way represents a fairly general case. The previous force and torque results give forms of the same type simplified somewhat by the equality of the coefficients, and the similarity—or absence—of the phase values. Any stated order of any given effect can be so reduced, and the same conception is thereby obtained of the essential elements of widely different actions. Further, this conception is wholly based on rotational quantities, and the study of resultants, or the balance of effects, is brought into direct and obvious relationship with the simple and analogous problem of rotating masses.

It is easily seen on examination of (21) that when

$$n\theta = \tfrac{1}{2}(\beta - \alpha)$$

the vectors P and Q are in the same straight line and in the same direction along it. The line in which they lie at that instant is set at the angle $(\alpha+\beta)/2$; and since P and Q then sum arithmetically, this is the direction of the maximum value of the force P_n. Again, at right angles to this, *i.e.*, at $(\alpha+\beta+\pi)/2$, the two vectors are in line but opposite in direction, and hence the minimum value is the difference of P and Q.

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The features just described may be more readily appreciated on reference to Fig. 8, in which the vectors are shown in posi-

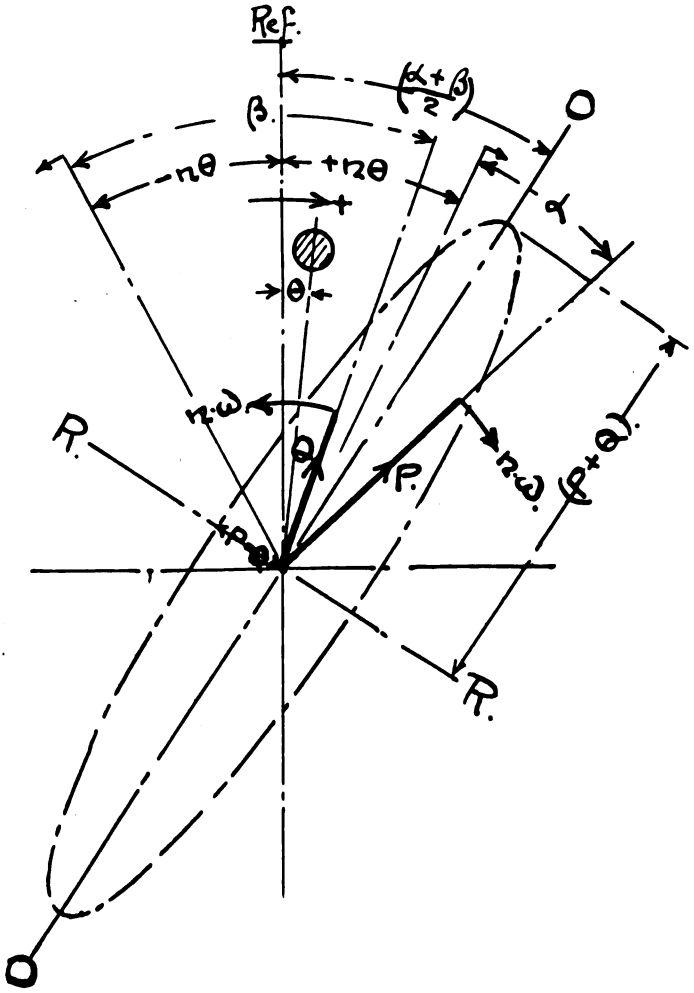

Fig. 8.

tion at one instant. From this it will be clear that P and Q are "in conjunction" along the line $\overline{OO}$ at the angle $(\alpha+\beta)/2$

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to the reference direction, and are "in opposition" along $\overline{RR}$, at right angles to $\overline{OO}$. It is readily deduced from (21) that the variation of the vector sum of P and Q is represented by an ellipse, of which $(P+Q)$ is the semi-major axis—along $\overline{OO}$—and $(P-Q)$ is the semi-minor axis—along $\overline{RR}$. This ellipse is shown in Fig. 8.

The facts established mean that in the general case of any force or torque there is "elliptic harmonic variation" of the quantity, the maximum value being given by the numerical sum of the vector magnitudes. And the direction of the maximum is easily derived from the phase angles α and β, established in the determination of the vector form of the given order. Since, in many cases, it is only maximum and minimum values that are required, it is clear that the problem is really solved when the appropriate vector expression has been obtained.

In the case in which the two oppositely rotating vectors are equal in length, $P-Q=0$, and the general elliptic variation reduces to simple harmonic variation. This is the case of the frame force, and also of the torques, previously considered. In connection with torque, it will be understood that, according to convention, the vector is supposed set off along the axis of torque, and, hence, the condition of equal forward and reverse coefficients means simple harmonic variation of an axial vector.

The process now established for the representation of the general harmonic order is an essential matter in all the subsequent discussion. In the consideration of any effect in any engine the purpose is merely to derive the representative double vector expression, and therefrom at once to obtain extreme values.

Geared Balance Weights. It should be noticed that the standard form of expression which has been developed, corresponds exactly with the method of balancing by means of weights geared from the shaft to rotate at the correct speed. The method is exemplified by the well-known "Lanchester Harmonic Balancer." This is a mechanical appliance directly analogous to the equation for frame force. Used in a four-

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cylinder petrol engine, it would be required to balance the force

$$\overline{F}_2 = (2b_2)e^{i2\theta} + (2b_2)e^{-i2\theta}$$

which means that a force has to be produced opposite to this, *i.e.*, the balancing force is expressed as

$$-\overline{F}_2 = -(2b_2)e^{i2\theta} - (2b_2)e^{-i2\theta}$$

This simply states that if a weight when rotating at twice the crank speed sets up a centrifugal force of $(2b_2)$ in magnitude, then two such weights geared to rotate in opposite directions will balance the total second order frame force. The negative sign merely defines the obvious fact that the weights would have to be set opposite to the (imaginary) double speed cranks. If, instead of rotating weights, complete wheels cored at appropriate places were employed, then the equation for the force to be balanced would also be the equation for the "cores."

In the case of more complex forces, balance by the Lanchester method could be effected with equal simplicity. It would only be necessary to make each weight of suitable magnitude and to set it in the correct phase position. Thus in order to balance the force

$$F_n = (Fe^{i\alpha})_n e^{in\theta} + (Ge^{i\beta})_n e^{-in\theta}$$

it would be necessary to have—

1. A weight w' at such a radius that its centrifugal force, for a rotational speed of (nw), is equal to F. The radial line of the weight would be set at $(-e^{i\alpha})$, *i.e.*, at $e^{i(\alpha+\pi)}$. It would be geared to rotate in the same direction as the crank, but at n times the speed.

2. A weight w'' that produces a centrifugal force equal to G at speed (nw). It would be set at $e^{i(\beta+\pi)}$, and geared to rotate at the nth speed, but in the opposite direction to the crank.

The mechanical problem is thus really the same for the simple and the general case, and this easily envisaged arrangement provides a direct means for the interpretation of the symbolical expressions. The mechanical device has only been

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actually applied in the simple case cited; but there is no real difficulty in more general application, and it is not impossible that it may attract further attention as a balancing process.

Opposed-Piston Double-Crank Arrangements. There are apparent differences in the various examples of this type, but in reality each is reducible to a piston-crank pair. Whether the case is that of opposed pistons in separate cylinders on opposite sides of the shafts, as in the opposed-cylinder type; or pistons within the same cylinder operating main and side cranks, as in the Doxford scheme; or "cross connected pistons" in side-by-side cylinders, as in the Cammellaird-Fullagar arrangement, each is readily seen to be equivalent to a double unit of the fundamental type already considered. The three cases mentioned may be taken as sufficiently representative of the range of the present classification. They are diagrammatically illustrated in Fig. 9, and a little consideration will show that the main problem lies in the proper combination of similar coefficients, with due regard to the configuration of cylinders and cranks. It might be noted as a general guidance that frame and torque effects should be combined on the basis of the cylinder arrangement, but that shaft forces require consideration of the crank scheme. Axial separation of the cranks affects the transverse shaft actions due to the forces, although the influence on the torque due to this cause is immaterial.

In the Cammellaird-Fullagar type of engine, Fig. 9 (a), the total motive force on the set of parts operated by the first crank comprises the action on the bottom piston of the first cylinder and that on the top piston, including the scavenging piston, of the second cylinder; and similarly for the second crank connected to the bottom of No. 2 and the top of No. 1. It is at once seen that the cross connection arrangement necessitates the existence of couples—in the vertical plane containing the crankshaft axis—acting through the medium of side forces on cylinder walls and guides. These couples are special consequences of this unique arrangement, but they are hardly of first importance; and arising, as they do, only in

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this one special case, they may be neglected in the interests of the more general study. The constancy of the angle of cross connection at all parts of the stroke renders it an easy matter to estimate the magnitude of these couples if and when necessary.

The determination of the motive force coefficients requires the employment of a composite pressure curve built up from two main cards and one scavenging pump card properly placed, and the combined card once obtained is examined for any order exactly as in the case of the simple engine. Beyond this the procedure is exactly as before, and, with the neglect of the special side couples of the type, the arrangement reduces in obvious fashion to the case of two simple sets, assembled close together. The representation of any effect for one set in vector notation follows the lines already given, and the expressions for the simple case are applicable here in unchanged form. For the purposes of analyses, the characteristic cylinder pair merely becomes equivalent to a two-cylinder engine with cranks at 180 degrees.

The more direct example of the opposed-piston type—the Doxford arrangement—is shown in Fig 9 (b). The bottom piston and its connections may be looked upon as one simple set; the contrary parts constitute another. But because all the main elements operate in a single line, it is desirable to refer all actions to the main crank, except the crank forces, which should be properly divided between the main and the two side cranks.

For the frame force in this case—using accented symbols for the top set—there is obtained

$$F_n = b_n \cos n\theta + b_n' \cos n\theta',$$

but, since $\theta' = \theta + \pi$, this becomes

$$\left.\begin{aligned} \overline{F}_n &= (b_n + b_n') \cos n\theta \text{ - - if } n \text{ is even} \\ &= (b_n - b_n') \cos n\theta \text{ - - if } n \text{ is odd} \end{aligned}\right\} \quad \text{(22)}$$

This states that the odd order frame forces are balanced if the crank-connecting rod ratios and the products of reciprocating masses and crank radii are equal for the opposing sets.

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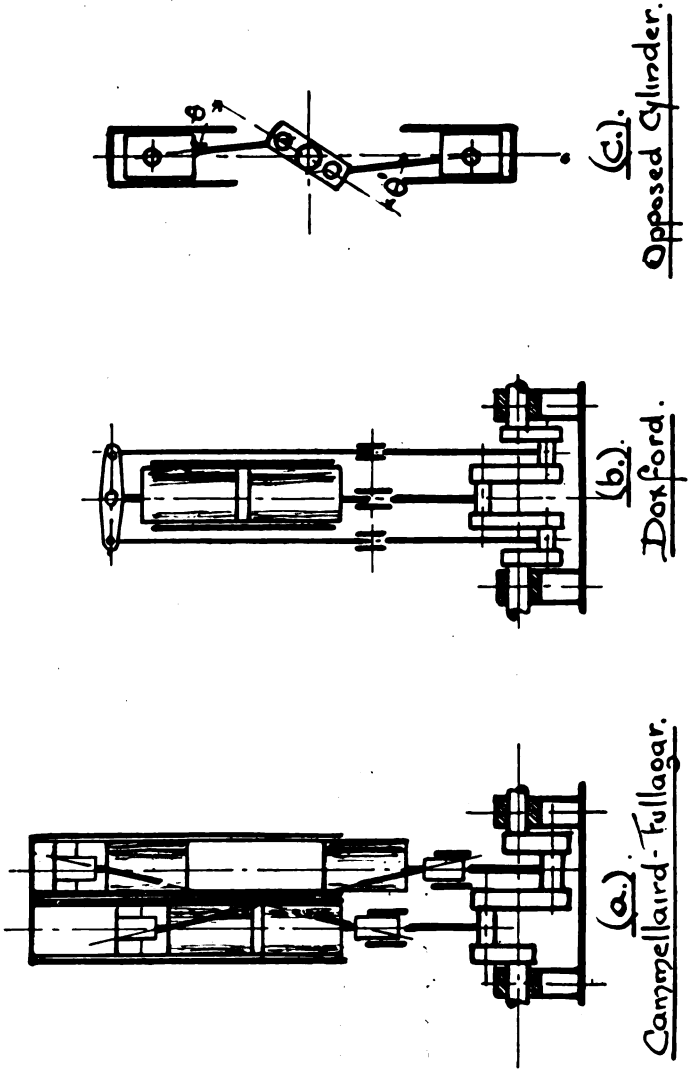

Fig. 39.—Opposed-Piston Double-Crank Types.

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The latter condition is deliberately arranged in the Doxford engine—the crank radii being made inversely as the reciprocating weights—so that the odd order forces are only out of balance to the small extent represented by any inequalities in the crank-connecting-rod ratios. Since these do not enter into the first order force coefficients, primary force balance is obtained. The second order force coefficients are additive, however, so representing unbalance in the elementary form.

Other effects involve the motive forces. These are obviously the same on both pistons, but opposite in direction. Coefficients for any order may be found for the bottom piston in the usual way, and the corresponding values for the top are then at once determinate, the only question being one of correct signs. Since the trigonometric ratios of $n\theta$ and $(n\theta + n\pi)$ have the same signs for n even, but change signs for n odd, and since the forces are equal but opposite, it follows that the Fourier coefficients for the bottom and top sets change sign only for even orders, if both forces are to be correctly expressed in terms of the main crank angle.

With the separate consideration of the two sets of parts, using first the descriptive crank angles θ and θ', and thereafter changing signs to suit the relation between these, any coefficient for any effect may be readily determined in terms of the main angle θ. In the cases of frame and shaft torques, algebraic summation of the coefficients should be made; for shaft forces, the proper quantities should be allocated to the respective cranks, but all based on θ. With the coefficients determined, the translation to vector form is by the usual procedure.

The essential points arising in connection with the opposed cylinder type, Fig. 9 (c), will be readily appreciated. It only marks a slight variation of the opposed-piston arrangement already considered. In this modification the two sets of parts are completely separated, and are arranged on opposite sides of the shaft. If the force systems, descriptively shown in Fig. 1 as characteristic of the single line, were introduced into the opposing sets of Fig. 9 (c), with the various values based on

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the two crank angles θ and θ', it would be at once seen that corresponding force effects in the two lines subtract, but that torque effects are additive. This is practically the whole matter in this type. There are certain differences between the opposed double-crank arrangement with cylinders on opposite sides of the shaft and that with the pistons on the same side. In the former all frame force orders balance; in the latter only odd orders do so. In the former the inertia terms in the two component torque actions add numerically for all orders; in the latter they are subtracted for odd orders. Driving torques, of course, add in both cases.

In the form of Fig. 9 (c) the driving forces in the two cylinders go through the same cycle, but are differently phased. The type may be considered as a complete engine in itself, or as the element of certain forms of static frame radial engines; but, however applied, it is mainly operated on the four-stroke cycle, and provides a simple illustration of the employment of the camshaft angle variable in such cycles.

If the cylinders are firing alternately, then, in effect, θ' is 2π ahead of θ. In terms of camshaft angles, represented by ϕ and ϕ', this means that ϕ' is π ahead of ϕ. All results obtained in terms of ϕ for the one line are equally applicable to the other if the angle symbols are accented. Direct combination by means of the rule—forces subtracted, torques added—is easily effected, and the results are then readily expressed in terms of the one angle ϕ by changing to suit the relation

$$\phi' = (\phi + \pi),$$

and may be further developed to suit the crank angle by means of $\theta = 2\phi$.

The discussion that has been given of the opposed-piston double-crank types should make it clear that all such arrangements reduce in quite a straightforward way, and that by the proper summation of numerical coefficients the final representation of the combined effects—in terms of a main or selected crank—is exactly in accordance with the fundamental case of the single line.

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Vee and Fan Cylinders—Single-Crank Arrangements. In these cases the lines of action are inclined to each other, but the parts in the several lines constituting the element are operated from a single crank.

Fig. 10 (a) represents the Vee arrangement diagrammatically. The two lines may be distinguished by single and double accents, and the crank position measured from the vertical as a reference. The single crank, however, really defines two crank angles—one for the right line and one for the left—and if the cylinders are inclined at λ to the reference, the crank positions for the two lines are

$$\theta - \lambda, \quad \text{and} \quad \theta + \lambda.$$

The arrangement is mainly used on the four-stroke cycle, and in such a case with the crank angles measured, as they ought to be, from the respective "firing dead centres," the proper representations of these angles are

$$\theta' = \theta - \lambda \;\; ; \;\; \theta'' = \theta + \lambda - 2\pi.$$

When changed into the camshaft notation, these become

$$\phi' = \phi - \tfrac{1}{2}\lambda \;\; ; \;\; \phi'' = \phi + \tfrac{1}{2}\lambda - \pi,$$

the firing conditions being given by $\phi' = 0,\ 2\pi,$ - -, and $\phi'' = 0,\ 2\pi,$ - -.

It has been shown that the frame force for a single line can be stated in the form of equation (18), which in the present case, with camshaft angles in use, gives for the separate lines

$$F_n' = (F)_n' e^{in\phi'} + (F)_n' e^{-in\phi'}, \text{ and } F_n'' = (F)_n'' e^{in\phi''} + (F)_n'' e^{-in\phi''}$$

These two forces act in directions inclined respectively $+\lambda$ and $-\lambda$ to the reference direction. Hence, assuming that the two lines are similar in all respects—which makes the F values all alike—the total frame force is

$$F_n = F_n(e^{in\phi'} + e^{-in\phi'})e^{i\lambda} + F_n(e^{in\phi''} + e^{-in\phi''})e^{-i\lambda}$$

and when the values of ϕ' and ϕ'' are introduced, this becomes

$$F_n = F_n\{e^{i(n-2)\frac{1}{2}\lambda}e^{-in\pi} + e^{-i(n-2)\frac{1}{2}\lambda}\}e^{in\phi} + F_n\{e^{i(n+2)\frac{1}{2}\lambda} + e^{-i(n+2)\frac{1}{2}\lambda}e^{in\pi}\}e^{-in\phi}$$

2z

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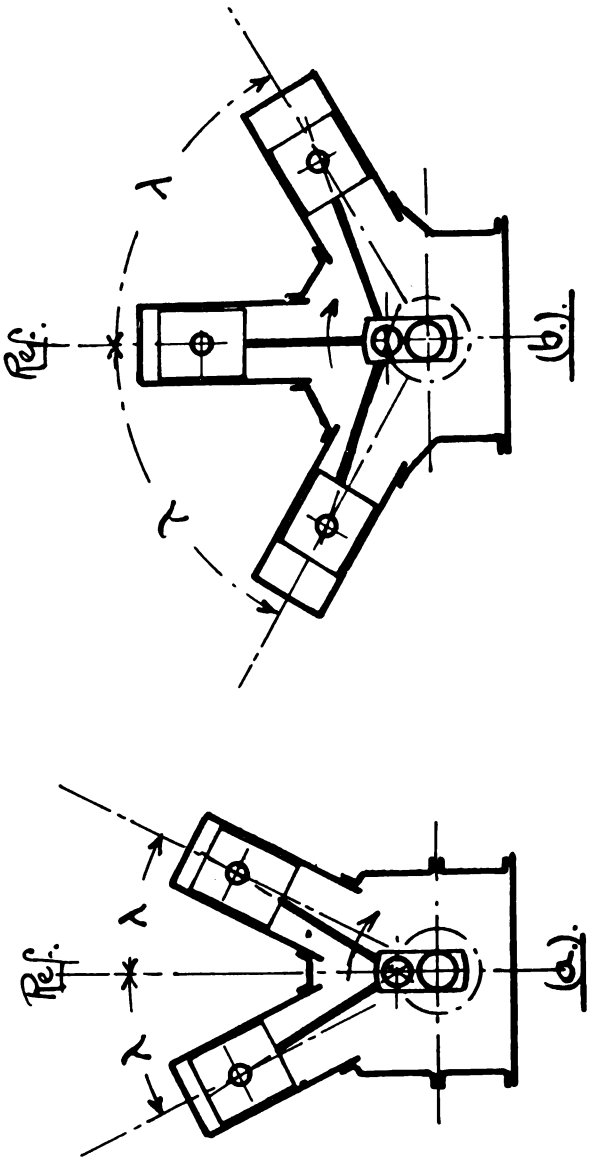

Fig. 10.—Vee and Fan Types.

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and this directly reduces to

$$\left.\begin{aligned}\bar{F}_n &= \left\{F_n \cdot 2\cos(n-2)\frac{\lambda}{2}\right\}e^{in\phi} + \\ &\quad \left\{F_n \cdot 2\cos(n+2)\frac{\lambda}{2}\right\}e^{-in\phi} \text{ - - if } n \textit{ is even} \\ &= \left\{F_n\left(-i2\sin(n-2)\frac{\lambda}{2}\right)\right\}e^{in\phi} + \\ &\quad \left\{F_n\left(i2\sin(n+2)\frac{\lambda}{2}\right)\right\}e^{-in\phi} \text{ - - - - if } n \text{ is odd}\end{aligned}\right\} \quad (23)$$

The double result here is only given for the purpose of illustrating the general interpretation. Actually the odd n values do not apply to frame forces which are dependent only on inertia terms, and, therefore, only on even "camshaft orders." But it is now clear that the effect of the angled arrangement of cylinders is to make the vector coefficients unequal, and hence the simple harmonic forces in the lines combine to give, in general, elliptic harmonic variation of the force on the complete frame.

If $\lambda = 45°$—the case of a 90° twin Vee—then the primary order force ($n=2$, when ϕ is used) is simply

$$(2F_2)e^{i2\phi} = (2F_2)e^{i\theta},$$

which is a vector rotating with the crank, and, therefore, represents a force that can be directly balanced by a weight placed opposite the crank. If $n=4$, the frame force is

$$(2F_4 \cdot \cos 45°)e^{i4\phi} + (2F_4 \cdot \cos 135°)e^{-i4\phi},$$

which represents simple harmonic variation in a direction at right angles to the reference, as can easily be seen by sketching the forward and reverse vectors described by the equation. If λ is taken at 30°, it may be shown by substitution in the main equation that the primary force is elliptic harmonic, and, therefore, can only be partly balanced by a weight opposite the crank, whilst the secondary is a purely radial force rotating at twice the crank speed. In this way it is easy to determine how the frame force alters in character with the Vee angle. The fact that it does so is, of course, generally expressed by equations (23).

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If the shaft torque be considered, equation (20) shows that it will be given by such an expression as

$$\overline{T}_n = (Te^{i\alpha})_n e^{in\phi'} + (Te^{i\beta})_n e^{-in\phi'} + (Te^{i\alpha})_n e^{in\phi''} + (Te^{i\beta})_n e^{-in\phi''}$$

the summation in this case being direct, since the two torques act in the same plane. On substitution for ϕ' and ϕ'', and reduction, this becomes

$$\left.\begin{aligned} T_n &= (T.2\cos n\tfrac{\lambda}{2}e^{i\alpha})_n e^{in\phi} + (T.2\cos n\tfrac{\lambda}{2}e^{i\beta})_n e^{-in\phi} \quad \text{- if } n \text{ is even} \\ &= (-Ti2\sin n\tfrac{\lambda}{2}e^{i\alpha})_n e^{in\phi} + (Ti2\sin n\tfrac{\lambda}{2}e^{i\beta})_n e^{-in\phi} \quad \text{- if } n \text{ is odd} \end{aligned}\right\} \quad (24)$$

In this case both results have an application since the torque involves the driving forces, and these contain all orders of ϕ. But it is quite clear that the standard form for torque in the single line arrangement still holds for the Vee scheme if the numerical coefficients and the phase angles are suitably modified. The same fact—and a similar relation—must apply, of course, to frame torques.

The shaft forces are combined exactly as the frame forces have been; and when it is recalled that even in the simple case the shaft force expression is of the most general type, it will be appreciated that no further complication beyond change of coefficient and phase is required to meet the case of the Vee arrangement.

It follows, then, that the standard vector expressions for the single line are adapted for the Vee arrangement by the procedure summarised as under:—

1. If n is even. For forces, multiply coefficients of the forward and reverse vectors by $2\cos(n-2)\frac{1}{2}\lambda$ and $2\cos(n+2)\frac{1}{2}\lambda$ respectively, phases α and β remaining unchanged. For torques, multiply both vectors by $2\cos n\frac{1}{2}\lambda$, phases again unchanged.

2. If n is odd. For forces, multiply respectively by $2\sin(n-2)\frac{1}{2}\lambda$ and $2\sin(n+2)\frac{1}{2}\lambda$, α and β being altered to $(\alpha-\frac{\pi}{2})$ and $(\beta+\frac{\pi}{2})$. For torques, multiply both vectors by $2\sin n\frac{1}{2}\lambda$ with same phase changes.

The three-cylinder fan arrangement is as sketched in Fig. 10 (b). The treatment for this is very similar to the last. The

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crank angles for the three lines—represented by single, double, and triple accents—are measured from the "firing dead centres" by

$$\theta' = \theta - \lambda \; ; \; \theta'' = \theta - 2\pi \; ; \; \theta''' = \theta + \lambda - 4\pi,$$

which gives the camshaft angle sequence

$$\phi' = \phi - \tfrac{\lambda}{2} \; ; \; \phi'' = \phi - \pi \; ; \; \phi''' = \phi + \tfrac{\lambda}{2} - 2\pi.$$

When the summations, as illustrated by the developments which have led to equations (23) and (24), are effected, the rules corresponding to those already given for the Vee assembly may be established as under:—

1. If n is even. For forces, multiply the coefficients of the forward and reverse vectors by $\{1+2\cos(n-2)\frac{\lambda}{2}\}$ and $\{1+2\cos(n+2)\frac{\lambda}{2}\}$ respectively. For torques, multiply both vectors by $\{1+2\cos n\frac{\lambda}{2}\}$. In all cases the phase angles α and β remain unchanged.

2. If n is odd. For forces, multiply respectively by $\{2\cos(n-2)\frac{\lambda}{2}-1\}$ and $\{2\cos(n+2)\frac{\lambda}{2}-1\}$. For torques, multiply both vectors by $\{2\cos n\frac{\lambda}{2}-1\}$. In all cases the phase angles are unaffected, although it should be noticed that a negative coefficient is equivalent to a positive coefficient with a phase change of π.

It will be recognised that the processes of examination and reduction which have been followed in this section of the paper are fully competent to deal with any elementary type, and with this the purpose of the section may be considered fulfilled. Rather a wide range of forms has been covered in a relatively short space, and, while completeness of detail presentation is thereby sacrificed to some extent, the main fact should be quite clear. No matter what may be the form or grouping of the engine parts that constitute the type, and no matter how they may act in association with, or in the plane of, the reference crank, it is always possible to make the same type of expression serve for any kind of effect in all of the forms. The expressions may be named and enumerated thus:

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$$\left.\begin{aligned}
\text{Frame force} &= \bar{F}_n = (Fe^{i\alpha})_n e^{in\theta} + (Ge^{i\beta})_n e^{-in\theta} \\
\text{Frame torque} &= \bar{K}_n = (Ke^{i\alpha})_n e^{in\theta} + (Ke^{i\beta})_n e^{-in\theta} \\
\text{Shaft torque} &= T_n = (Te^{i\alpha})_n e^{in\theta} + (Te^{i\beta})_n e^{-in\theta} \\
\text{Shaft force} &= \bar{P}_n = (Pe^{i\alpha})_n e^{in\theta} + (Qe^{i\beta})_n e^{-in\theta}
\end{aligned}\right\} \quad (25)$$

All these statements are interpreted in the same way. The α and β symbols represent general phase angles for the nth order symbol to which they are attached. Where the coefficients of the forward and reverse vectors are equal, the phase angles are really equal in magnitude but are of opposite sign. The different coefficient symbols mark the different actions; change of values of any symbol and its phase would be a consequence of change of the engine type; but when the values for any specified form have been established—by the methods described—it is quite unnecessary to make further reference to the details of the coplanar grouping of parts that characterise the type.

In this way the actions within the element are simply reduced to force and torque effects in one plane. It is generally best to consider that all the actions stated are really present in that plane. It is only in certain special cases that balance of any kind is achieved within the element, and these cases are confined to the opposed-piston types. Thus it has been shown that the frame force is wholly eliminated in the opposed-cylinder combination, and that the odd orders of that force are balanced in the opposed-piston types. In the latter cases there is also some degree of cancellation of inertia components in the torque effects; and, of course, the shaft forces are largely balanced, although by arrangements which do not necessarily free the shaft from bending influences. In one case, then, one effect is eliminated; in others of a similar class some effects are ameliorated; but, in general, the engine element establishes the four standard effects in its plane of action.

Multiple Engines—Frame Effects.

The term multiple engine is here used to represent the group arrangement of elementary forms obtained by repeating these

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forms in parallel planes spaced at intervals along the shaft length. Each element is associated with its own crank, and the successive cranks have a definite angular sequence determined by the firing order of the engine. It has been shown that the element creates certain actions in its plane which are duly related to its crank, and hence, in general, effective balance and residual unbalance in the complete engine must ultimately depend upon firing orders and the number of elements comprising the group.

What might be termed the "degree of multiplicity" of the engine is simply the number of the single planes in which the elementary actions are repeated. The main consequences of the mode of discussion adopted in the previous section are to be found in the freedom with which the multiple engine can be treated without specific reference to type. The expressions of (25) are applicable to any type—assuming that correct numerical values have been obtained in actual cases—and hence a "multiple four" engine may be a four-cylinder petrol engine, a four-cylinder opposed-piston engine, an eight-cylinder Vee engine, a twelve-cylinder fan engine, and so on. In each of these there are only four representative planes of action.

The discussion of total engine effects may, for present purposes, be confined to main engine elements. The actual engine may, of course, contain pump or compressor lines in addition, or pumps may be operated by side levers from a main element. In all such cases the additional parts constitute an extraneous system whose actions have to be superposed on those of the main engine. But since they involve entirely different quantities, of lesser magnitude, and of rather unsymmetrical disposition, it is desirable that they should be considered apart. The auxiliary lines are always limited in number, and there is no real difficulty in dealing with them separately and including them after the summations for the main engine have been effected. The individual auxiliary elements are treated by the methods already outlined, and their association with the engine is fully covered by the use of the same reference angle or plane.

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Frame Forces. The total frame force of a multiple engine is merely the sum of the separate frame forces of the elements, due regard being paid to the phasing of the cranks. The crank angles in the successive planes, 2, 3, - - may be adequately expressed by means of the angles δ_2, δ_3 - - with which they lead No. 1 crank. It will be understood that in the four-stroke cycle the same notation refers to camshaft angles. Results may, in general, be written for the two-stroke case, and interpreted for the four-stroke scheme as necessary. If, then, the various crank angles are

$$\theta_1,\ \theta_1+\delta_2,\ \theta_1+\delta_3,\ \text{- - -},$$

it follows that the total frame force of the general order is

$$\begin{aligned}\bar{\bar{\mathrm{F}}}\bar{\bar{\mathrm{F}}}_n = {} & (\mathrm{F}e^{i\alpha})_n e^{in\theta_1}[1+e^{in\delta_2}+e^{in\delta_3}+\text{- -}] \\ & +(\mathrm{G}e^{i\beta})_n e^{-in\theta_1}[1+e^{-in\delta_2}+e^{-in\delta_3}+\text{- -}] \quad \text{- - -} \quad (26)\end{aligned}$$

the double symbol $\bar{\bar{\mathrm{F}}}\bar{\bar{\mathrm{F}}}$ being used to distinguish the group from the element.

It is obvious that the nature of the sum is decided by the expressions within square brackets in (26). Now, the first of these is the sum of a series of *unit* vectors set off in succession at angles 0, $n\delta_2$, $n\delta_3$, - - - ; and the second is a similar set of unit vectors at angles 0, $-n\delta_2$, $-n\delta_3$, - - -. The first is associated with the forward vector, the second with the reverse vector; and the two summations are entirely similar. The nature of the result is, therefore, most readily found by examining one series. If the frame force is balanced, this series must equal zero; and hence the criterion of balance is simply

$$[1+e^{in\delta_2}+e^{in\delta_3}+\text{- - -}]=0 \quad \text{- - -} \quad (27)$$

Thus, in a multiple four group, firing 1, 2, 4, 3, 1, the crank leads are given by

$$\delta_2=270^\circ,\ \delta_3=90^\circ,\ \delta_4=180^\circ,$$

and the representative summation is

$$\left(1+e^{in\frac{3}{2}\pi}+e^{in\frac{1}{2}\pi}+e^{in\pi}\right)$$

This will be readily followed from Fig. 11, which shows the

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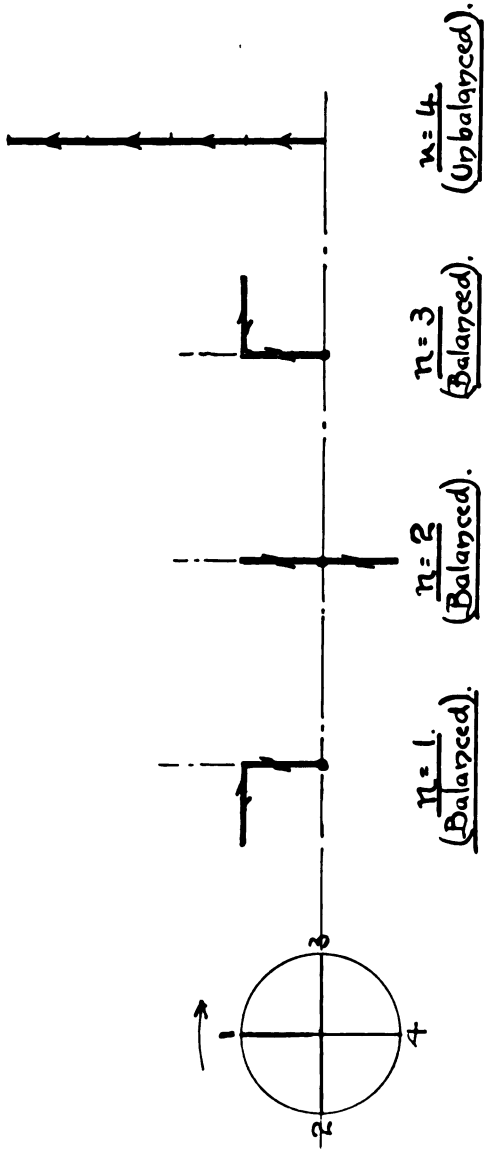

FIG. 11.

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sums for values of n from 1 to 4, and discloses the fact that the first three orders are balanced, but the fourth is not. If continued further, it would be shown that the eighth was the next unbalanced order. In fact, all multiples of 4 represent unbalanced orders; and, since at these values the unit vectors add in line, it follows that the unbalanced effect for the group is merely four times that of the element.

If any other group number were taken with the cranks in an equally spaced angular setting around the circle, a similar result would be reached. Always the orders that are multiples of the number of cranks are unbalanced. This is a well-known result for symmetrical crank schemes, and, in the terminology of this paper, may be concisely expressed by the statement that the unbalanced frame force orders are integral multiples of the group number.

The same rule applies to the four-stroke case if camshaft orders are understood. The multiples have then to be divided by two to obtain the equivalent crank orders. Thus, whilst in a multiple four two-stroke engine the unbalanced crank orders are 4, 8, 12 - -, in a similar four-stroke they are $\frac{4}{2}$, $\frac{8}{2}$, - -; in a multiple six two-stroke they are 6, 12 - -, and in a six group four-stroke are $\frac{6}{2}$, $\frac{12}{2}$ - -. Since the frame force only involves inertia terms, and since the third order term is absent, it follows that there is a large difference between the lowest order unbalanced forces in the four and six group four-stroke arrangements. The former is out in the relatively large second order, and the latter in the minute sixth order. This is an essential difference in the balance of these two important petrol engine types.

The whole matter of the total frame force is, then, contained in the general facts stated above, namely, the unbalanced orders are integral multiples of the group number, and the magnitude of any such order is that of the element multiplied by the group number. Hence the problem of frame force really depends on the determination of the value for the element. The rule does not hold, of course, if there is unequal crank spacing. In such a case all orders would be unbalanced

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to a varying extent only to be determined by the summation of the unit vector sequence.

Frame Torques. Theoretically the summation for total frame torque is similar to the case of forces just considered, and leads to the same general conclusions. The frame forces, however, only include inertia terms which are rapidly convergent, whereas the frame torque series involves the consequences of the motive forces, and may contain a wide range of orders of real significance. Thus a four group two-stroke may be said to have no unbalanced frame force worthy of attention because the fourth order is of very small magnitude. But, while the same line of reasoning to that for forces will show the fourth order torque to be unbalanced, the same conclusion cannot be reached regarding its unimportance, because the fourth order torque is not necessarily small in amplitude. Following the method already given, the total frame torque of the nth order is

$$\begin{aligned}\bar{F}T_n = (Ke^{i\alpha})_n e^{in\theta_1}[1 + e^{in\delta_2} + e^{in\delta_3} + \text{- -}] \\ + (Ke^{\beta})_n e^{-in\theta_1}[I + e^{-in\delta_2} + e^{-in\delta_3} +]\end{aligned} \quad \text{- (28)}$$

and again the criterion of balance is

$$[1 + e^{in\delta_2} + e^{in\delta_3} + \text{- -}] = 0 \quad \text{- - - (29)}$$

and the consideration of this leads, in the same way as before, to the general result that the unbalanced total frame torque orders are integral multiples of the group number, and the magnitude of any unbalanced order is that of the element multiplied by the group number.

Since there is a zero order component in the frame torque series, integral multiples will require to be taken as 0, 1, 2 - - - ; and thus an eight cylinder in line, two-stroke, engine has unbalanced torques of the 0, 8, 16 - - crank orders; while an eight-cylinder Vee four-stroke engine—a four group arrangement—is out in the 0, $\frac{4}{2}$, $\frac{8}{2}$ - - crank orders. The zero order is, of course, merely the mean turning-moment due to the drive, and is easily estimated; and if the few unbalanced orders are superposed on this, the total frame torque curve may readily be established, although such a procedure is probably more important in the case of shaft torques.

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The above remarks refer to the unbalanced effects for the frame as a whole; they define the cyclic torque orders which tend to oscillate the complete frame about the shaft axis. In light frames, however, or where stresses due to torque reaction have to be considered, it may on occasion be necessary to deal with torque values at some chosen position. In such cases the summation has to be limited to the appropriate terms of the torque series in (28). The same point arises more definitely in connection with the shaft, where the corresponding question would be the torque at, say, any selected journal. The step from the complete to the partial treatment of such matters marks a change in the problem from dynamics to elasticity; but although body balance and vibratory stress are conditions apart from each other, they are both important, and it is not always clear that in frame design *all* the consequences of torque reaction are adequately considered.

Frame Couples. The total frame force is the resultant of what is really a distributed system of forces, but because of the distribution the system must also, in general, give a couple effect. If a plane of reference is taken, through, say, the C.G. of the frame, the complete set of elementary frame forces is equivalent to the total force—already considered—acting in this plane, together with a resultant couple, which is the sum of the moments of all the forces about the plane. The plane of reference is usually taken as the central plane of the frame length embodying the main engine units—see Fig. 12.

If the distances of the several elements from this plane be given by a_1, a_2, - - -, then the moment of the force in line 1 is

$$(\mathrm{F}e^{i\alpha})_n a_1 e^{in\theta_1} + (\mathrm{G}e^{i\beta})_n a_1 e^{-in\theta_1}$$

and hence the total frame couple of the general order is

$$\begin{aligned}\overline{\mathrm{FC}}_n = {} & (\mathrm{F}e^{i\alpha})_n e^{in\theta_1}[a_1 + a_2 e^{in\delta_2} + a_3 e^{in\delta_3} + \text{ - - }] \\ & + (\mathrm{G}e^{i\beta})_n e^{in\theta_1}[a_1 + a_2 e^{-in\delta_2} + a_3 e^{-in\delta_3} + \text{ - -}] \quad \text{-} \qquad (30)\end{aligned}$$

and by direct vector summation of the bracketed series it is easy to determine the nature and value of the couple when the particulars are known. It will be observed that the summation will give numerical factors modifying F and G, and

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directions modifying the phases α and β; so that this new case also reduces to the standard form. The characteristics of the couple are really contained within the brackets, and, although it is obvious that the simplicity of a set of unit vectors no longer exists, it will be clear that the condition of couple balance is

$$[a_1 + a_2 e^{in\delta_2} + a_3 e^{in\delta_3} + \text{- -}] = 0.$$

In a simple two group engine, since $a_1 = -a_2$, this would give

$$a_1(1 - e^{in\delta_2}) = 0,$$

from which it appears that balance is only possible if $n\delta_2 = 0$, 2π - -, so that nth order balance requires that the "nth order cranks" should be in line.

This is the only really general fact in this part of the subject, and it is easily recognised from this simple case. With two actual cranks at 90 degrees the couples would be unbalanced until the fourth order ($4 \times 90° = 360°$); with the cranks at 180 degrees the second order would be balanced. These results apply no matter which of such diverse forms as a simple two-cylinder engine, a two-cylinder Cammellaird-Fullagar, or a double group static radial arrangement is considered, although, of course, there is no couple of a theoretically unbalanced order if there are no elementary plane forces of that order.

In a triple group set, the central plane would be at No. 2. The balance condition is

$$a_1(1 - e^{in\delta_3}) = 0,$$

and if $\delta_3 = 240$ degrees there is balance of the 3, 6 - - orders.

The important practical engines comprise four groups and upwards. In any multiple four the state of couple balance is expressed by

$$a_1(1 - e^{in\delta_4}) + a_3(e^{in\delta_2} - e^{in\delta_3}) = 0 \quad \text{- -} \quad (31)$$

and this shows that

$$n\delta_4 \text{ and } n(\delta_3 - \delta_2)$$

must both be multiples of $\pm 2\pi$. It will be clear that, with any possible distribution of cranks in the two-stroke system,

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the first order cannot be balanced on this principle; but the second order can, since it is possible to have

$$2\delta_4 \text{ and } 2(\delta_3 - \delta_2) = \pm 2\pi.$$

This simply gives the well-known firing sequences 1, 2, 4, 3 and 1, 3, 4, 2, with 90 degrees intervals. It will be recalled that the second order as so discussed corresponds to the primary order in the four-stroke cycle; and since with the sequences as above defined all higher even orders are necessarily in balance, the four-stroke system based on these is in full couple balance. The similar two-stroke arrangement is out in the primary order only; but the two-stroke sequence 1, 4, 2, 3 is not in couple balance below the fourth order.

In the case of primary unbalance considered, the couple would be non-existent if the primary force of the element were eliminated. This is a procedure possible in certain types, of which the Doxford engine is a good example, and the deliberate steps taken in recent designs of this type to ensure the elimination of the first line forces suggests the great importance of these primary couple effects in large engines. The Vee and fan types with certain divergence angles may have their primary forces effectively countered by means of a simple balance weight, so that such forms used on two-stroke operations could easily be arranged for couple balance. On the four-stroke system they are, as already shown, in self-balance.

Again, it should be noticed that in (31) there are two terms, and besides the features of that expression already derived, there is the further theoretical condition of

$$\frac{a_1}{a_2} = -\left(\frac{e^{in\delta_2} - e^{in\delta_3}}{1 - e^{in\delta_4}}\right),$$

which would call for a special choice of angles and pitching. Any attempt to meet this would mean departure from the internal-combustion engine principles of equal crank intervals and equal cylinder pitches. When the adjustment of reciprocating masses is associated with the special crank spacing, the process defined by this expression leads to the well-known "four crank symmetrical" steam engine arrangement.

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In a multiple six group we should have for balance

$$a_1(1 - e^{in\delta_6}) + a_2(e^{in\delta_2} - e^{in\delta_5}) + a_3(e^{in\delta_3} - e^{in\delta_4}) = 0 \quad - \quad (32)$$

and the usual condition would require

$$n\delta_6 = n(\delta_5 - \delta_2) = n(\delta_4 - \delta_3) = \text{multiple of } \pm 2\pi.$$

Again, it is clear that this cannot be satisfied for the first order, but can for the second by any arrangement that puts 1 and 6, 2 and 5, 3 and 4 opposite each other. If thus suited for the second, balance of all higher even orders is naturally obtained, and, as in the last case, this means that the usual six group four-stroke firing orders give full couple balance. But in two-cycle engines any sequence satisfying the above requirement of opposite cranks fails to give primary balance. Again, this may be effected in special cases by the elimination of primary forces in the element. But beyond this, primary balance, if specially sought, and not necessarily entailing secondary balance, may be obtained by satisfying the balance equation in the forms

$$\left.\begin{aligned} a_2(e^{i\delta_2} - e^{i\delta_5}) &= -\{a_1(1 - e^{i\delta_6}) + a_3(e^{i\delta_3} - e^{i\delta_4})\} \\ a_1(1 - e^{i\delta_5}) &= -\{a_2(e^{i\delta_2} - e^{i\delta_5}) + a_3(e^{i\delta_3} - e^{i\delta_4})\} \end{aligned}\right\} \quad - \quad (33)$$

The general solution of these is too involved to be worthy of attention, but a little consideration will show that they are, respectively, satisfied by the sequences 1, 6, 2, 4, 3, 5 and 1, 4, 5, 2, 3, 6. The former requires that

$$2a_2 = a_1 + a_3,$$

while the latter necessitates that all cylinder pitches should be equal.

In a multiple eight engine there is an additional term in the balance condition, making it

$$a_1(1 - e^{in\delta_8}) + a_2(e^{in\delta_2} - e^{in\delta_7}) + a_3(e^{in\delta_3} - e^{in\delta_6}) + a_4(e^{in\delta_4} - e^{in\delta_7}) = 0 \quad (34)$$

and the straightforward interpretation gives an obvious arrangement of opposite cranks for second order balance. The formal discussion of (34) is neither desirable nor necessary, as a slight consideration of the opposite crank sequence, which it directly suggests, shows that the system is equivalent to two

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sets of four, each in secondary balance; and any such double set would give a similar degree of balance. There is a large number of such groups possible, and it is a relatively easy matter to establish them; but while all are in second order balance, they give rise to different primary couple values, depending mainly on the extreme lengths of frame occupied by each group of four elements. It is then readily understood that the least primary couple will be created if the two groups are respectively 1 to 4 and 8 to 5. Within these groups, the sequences must follow those of a four group engine in secondary balance.

The study of any proposed arrangement with a large number of elements is best conducted graphically, as illustrated in Fig. 12, which shows the values of the expression in (34) for two selected sequences for eight elements. The numbered couples are really proportional to the lengths shown by the heavy lines.

In arrangements with odd numbers of elements—as five or seven—having equal crank intervals, it is obviously impossible to have couple balance except for those orders satisfying the condition

$$n\delta = \text{multiple of } 2\pi.$$

These naturally balanced orders are of little consequence, and, in general, such arrangements will have no balance of couples. If the crank angles were specially arranged to minimise any such effects, uneven firing impulses and frame force unbalance would ensue, and a nice discrimination would have to be exercised to determine how far such a process could be carried.

If pump and compressor lines are incorporated with the main engine, their couple effects must also be taken about the central plane. The positions of these lines will clearly have an influence on the total couple, and it is probably most desirable that their crank angles should be arranged as far as possible to counteract the couple effects of the main engine group.

The section just concluded has endeavoured to review the frame effects in a general fashion. The main point lies in the

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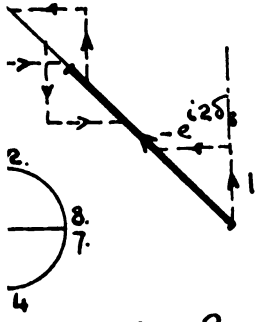
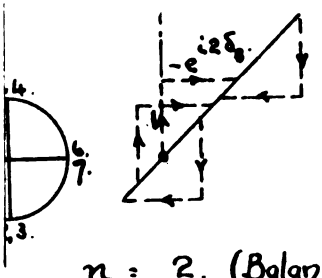


Sequence
1,6,4,7,2,5,3,8.

$n = 2$.

Sequence
1,8,3,6,4,5,2,7.



$n = 2$. (Balanced.)

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fact that the grouping of elements to provide the multiple engine forms common in internal-combustion engineering is very easily considered, analytically or graphically, by means of the typical series involving the crank sequence, and represented in the more general case by the couple series given in (34). When these series have been evaluated, the original double vector forms are again concisely established, by simple modification of the magnitude and phase values of the appropriate action in No. 1 element.

Multiple Engines—Shaft Effects.

Shaft Torques. The summation of shaft torques is similar to that for the frame actions of the same kind. These two torques only differ in value to a minor degree, and they are similarly distributed. The general facts already given for one set apply equally to both.

The unbalanced shaft torque orders are, then, for the complete engine system, the integral multiples of the group number; and the magnitude of any such unbalanced order is that for the element multiplied by the group number. It is, therefore, a simple matter to appreciate the components of the complete torque curve for any engine, and it is quite unnecessary to determine all the orders of the elementary torque if the sole aim is to establish the total torque curve for the group. This total torque is simply formed by the unbalanced orders superposed on the mean driving moment, and in multiple engines the unbalanced orders are comparatively few in number.

Thus in, say, a six-cylinder two-stroke engine, the unbalanced torque orders are 0, 6, 12 - - -, and the amplitudes of these are each six times that of the corresponding value for one cylinder. It follows, then, that the shaft torque is

$$6(\overline{T}_0 + \overline{T}_6 + T_{12} + \text{- -}),$$

and there are really very few components to consider. If the engine operated on the four-stroke cycle, the above would refer to camshaft orders.

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These summed unbalanced orders are the important quantities in the consideration of fly-wheel effects. But they are also of main significance in connection with torsional oscillations. The values $6\overline{T}_6$ and $6\overline{T}_{12}$ represent periodic disturbing torques that will be active in establishing and maintaining resonant vibration at the appropriate critical speeds. A "first degree twelfth order critical" is merely the rotational speed at which the twelfth order unbalanced torque fluctuations would be in agreement with the natural torsional single-noded vibration frequency. A "second degree" implies two nodes, and so on. But, while it is obvious that these large torque fluctuations, building up progressively as they do along the shaft, are of first importance in this matter, there are others that cannot be ignored. These are the orders that, while balanced in the whole engine range, are cumulative in part lengths, and are, therefore, forcefully active within the limits of the elastic system, and so quite capable of establishing vibration.

Thus, considering the six-cylinder engine as before, firing, say, 1, 6, 2, 4, 3, 5, the torque after any crank depends on the number of terms of the series

$$\left(1 + e^{in\frac{4}{3}\pi} + e^{in\frac{2}{3}\pi} + e^{in\pi} + e^{in\frac{1}{3}\pi} + e^{in\frac{5}{3}\pi}\right)$$

Beyond the first crank all orders are present, since only the torque of one element acts. After the second all orders are still active, but the 3rd, 6th, 9th - - are doubled in value, the others remaining as before. Beyond the third crank only the 3rd, 6th, 9th - - exist, but at three times the elementary value. The fourth crank reduces the 3rd, 9th - - to double value again, increases the 6th, 12th - - to quadrupled value, and reintroduces the others. The actions of the fifth and sixth cranks lead to the cancellation of all except the 6th, 12th - - previously given as the main unbalanced orders of the complete system.

It is clear, then, that the shaft at various places in its length is subjected to the actions of the fluctuating torques of all orders. There are main effects of the 6th, 12th - - orders, medium influences of the 3rd, 9th, 15th - - orders, and small

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influences of the others. All of these are theoretically capable of causing critical conditions, but in actual systems probably only a few of the lower orders in each of the specified sets are of real importance. Even at that, however, they are too numerous to be completely evaded, and, in connection therewith, it is of great importance that the relative powers of different torque amplitudes and frequencies to establish serious torsional vibration should be determined by investigation.

Shaft Moments. It has been shown that the shaft torque at any position between cranks is readily found. These positions are usually where bearings are situated, and at the same places the shaft is strained over the bearing support by a bending-moment the determination of which is essential to the examination of shaft stresses. It is only by the consideration of these "bearing-moments" that the shaft can be properly reduced to a single span length for stress discussion. It appears to be customary in the "stressing" of a crankshaft either to carry out an elaborate examination with a set of instantaneous loads on the several spans, or, alternatively, to make assumptions whereby a single span may be dealt with directly.

Neither of these methods can be considered complete. The loading has a time factor, and can only be properly treated by a vector procedure. In such a method, however, the straining-moments at the bearings for the different orders are separately determined. This may be considered a disadvantage where the whole purpose is to derive total stress values irrespective of rapidity of fluctuation, but a clear view of the stress conditions must envisage this feature.

If the shaft torque and the straining-moment at any journal are known for a particular order, it follows that the range of the principal stresses in the material at that place and for that order can be readily obtained; and this range is directly associated with the rate of fluctuation. This is important in the study of fatigue actions in the shaft, for the stresses of various orders represent stress reversals superposed on the steady value corresponding to the main conditions. These magnitudes and rates of alternation are completely

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obscured in the usual methods of calculation, but they must be admitted as of importance in any judgment of the severity of the shaft actions.

The introduction of shaft stress questions into a discussion of balance may be considered rather inappropriate, but it is not really so. A complete view of balance must include the recognition of vibratory stresses as well as periodic body forces and torques. Unbalanced torques produce torsional oscillations, but it is the stress actions due to these that are dangerous. Transverse force systems may not be in unbalance as a whole, but their distribution involves vibratory stresses that may require attention. All the consequences of the dynamical actions should be recognised, and fatigue failure due to vibratory stresses is not the least serious of these.

It is not the purpose here, however, to enter deeply into these questions, as adequate treatment would require to be lengthy, but it appears desirable to indicate how the important "indeterminate" shaft-moments of any order may be developed.

The shaft is in similar condition to a continuous beam, but is loaded in the several spans by load systems that differ in phase only. Generally the shaft changes greatly in flexural rigidity within a span length, due to web and pin constructions, but the exact repetition of the form and the loading in all spans allows the assumption of uniform rigidity to be made with fair accuracy. It is, of course, only for the examination of the moments at the bearings that this assumption is permissible. When these are found each span is a fully determinate beam system in itself, and can be examined for stresses along its length with due regard to its variable form. But the conditions at the journal are, of course, completely established when the torque and straining-moments there are found.

The shaft force for any element is given by—see (25)—

$$P_n = (Pe^{i\alpha})_n e^{in\theta} + (Qe^{i\beta})_n e^{-in\theta}$$

expressing elliptic harmonic variation. If attention is directed to any chosen order the suffix n may be discarded, and P_1, P_2, P_3 - - - simply written for the forces arising in the

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different elements. Taking the difference of phase into account, it follows that

$$\bar{P}_2 = \bar{P}_1 e^{i n \delta_2}, \quad \bar{P}_3 = \bar{P}_1 e^{i n \delta_3}, \quad \text{- - .}$$

Consider the case of a multiple four engine with four equal spans and five bearings, giving the equivalent beam system shown in Fig. 13. The spans and bearings are referred to by Roman numerals are marked. If X and Y are defined by

$$X = \frac{6}{l}\left\{\begin{array}{l}\text{Moment of area of a "free" bending-moment diagram} \\ \text{about the left end of a span.}\end{array}\right\}$$

$$Y = \frac{6}{l}\left\{\begin{array}{l}\text{Moment of area of a "free" bending-moment diagram} \\ \text{about the right end of a span.}\end{array}\right\}$$

and if M, with appropriate suffix, denotes the moment at a

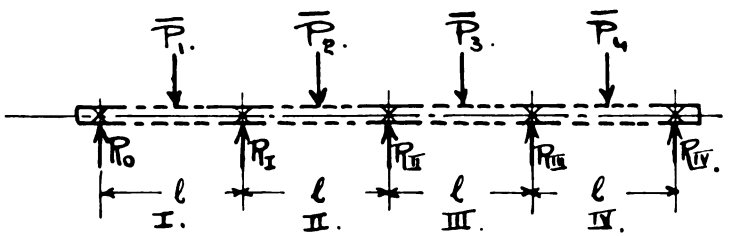

Fig. 13.

bearing, then the usual method for continuous beam calculation gives

$$\left.\begin{array}{l} M_0 l + 4M_I l + M_{II} l = X_I + Y_{II} \\ M_I l + 4M_{II} l + M_{III} l = X_{II} + Y_{III} \\ M_{II} l + 4M_{III} l \times M_{IV} l = X_{III} + Y_{IV} \end{array}\right\} \quad \text{- - -} \quad (35)$$

If the shaft may be considered free at the ends

$$M_0 = M_{IV} = 0,$$

and if the load on each span be taken as central

$$X_{II} = Y_{II}, \quad X_{III} = Y_{III}.$$

Then there follows by direct solution of (35)

$$\left.\begin{array}{l} M_I = \frac{1}{56} l \{ \quad 15X_I + 11X_{II} - 3X_{III} + X_{IV} \} \\ M_{II} = \frac{1}{56} l \{ - 4X_I + 12X_{II} + 12X_{III} - 4X_{IV} \} \\ M_{III} = \frac{1}{56} l \{ \quad X_I - 3X_{II} + 11X_{III} + 15X_{IV} \} \end{array}\right\} \quad \text{-} \quad (36)$$

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Now

$$X_I = \tfrac{3}{8}P_1 l^2, \quad X_{II} = \tfrac{3}{8}P_2 l^2 \text{ - - -},$$

and on substitution for X and $\overline{P}$ the equations for moments become

$$\left.\begin{aligned}
M_I &= \tfrac{3}{448}[(Pe^{i\alpha})e^{in\theta_1}\{15 + 11e^{in\delta_2} - 3e^{in\delta_3} + e^{in\delta_4}\} \\
&\quad + (Qe^{i\beta})e^{-in\theta_1}\{15 + 11e^{-in\delta_2} - 3e^{-in\delta_3} + e^{-in\delta_4}\}] \\
M_{II} &= \tfrac{3}{448}[(Pe^{i\alpha})e^{in\theta_1}\{-4 + 12e^{in\delta_2} + 12e^{in\delta_3} - 4e^{in\delta_4}\} \\
&\quad + (Qe^{i\beta})e^{-in\theta_1}\{-4 + 12e^{-in\delta_2} + 12e^{-in\delta_3} - 4e^{-in\delta_4}\}] \\
M_{III} &= \tfrac{3}{448}[(Pe^{i\alpha})e^{in\theta_1}\{1 - 3e^{in\delta_2} + 11e^{in\delta_3} + 15e^{in\delta_4}\} \\
&\quad + (Qe^{i\beta})e^{-in\theta_1}\{1 - 3e^{-in\delta_2} + 11e^{-in\delta_3} + 15e^{-in\delta_4}\}]
\end{aligned}\right\} \quad (37)$$

and again there appear series that involve the crank sequence. These may easily be summed graphically, and Fig. 14 illustrates this procedure for M_I for the crank arrangement 1, 2, 4, 3, with $n = 1$. By this means the moments are fully reduced, and it is clear that the straining-moment in the shaft at any bearing may be expressed by

$$SM_n = (Me^{i\alpha})_n e^{in\theta_1} + (Ne^{i\beta})_n e^{-in\theta_1} \quad \text{- - -} \quad (38)$$

This is of the standard form, giving a maximum moment of $(M + N)$ and a minimum of $(M - N)$. By consideration of a few simultaneous values of moments and torques, it would be possible to determine the range of principal stresses of the chosen order.

It is clear that any shaft arrangement may be dealt with by this method, but the different cases arising in practice are too numerous to be included here. With unequal spans the lengths, l_I, l_{II} - - - would finally appear in the bracketed series; with non-central or multi-line load on each span the X and Y values would be unequal, or would involve several P quantities. The elaborations are always in the crank sequence series, and vanish on graphical summation, leading to a clear definition of maximum and minimum straining-moments.

Bearing Reactions. Since the bearing reactions are functions of the loads and the straining-moments, it is clear that they also become determinate for any order when these moments have been found. The examination of bearing reactions is an important item in design; and although there may be less

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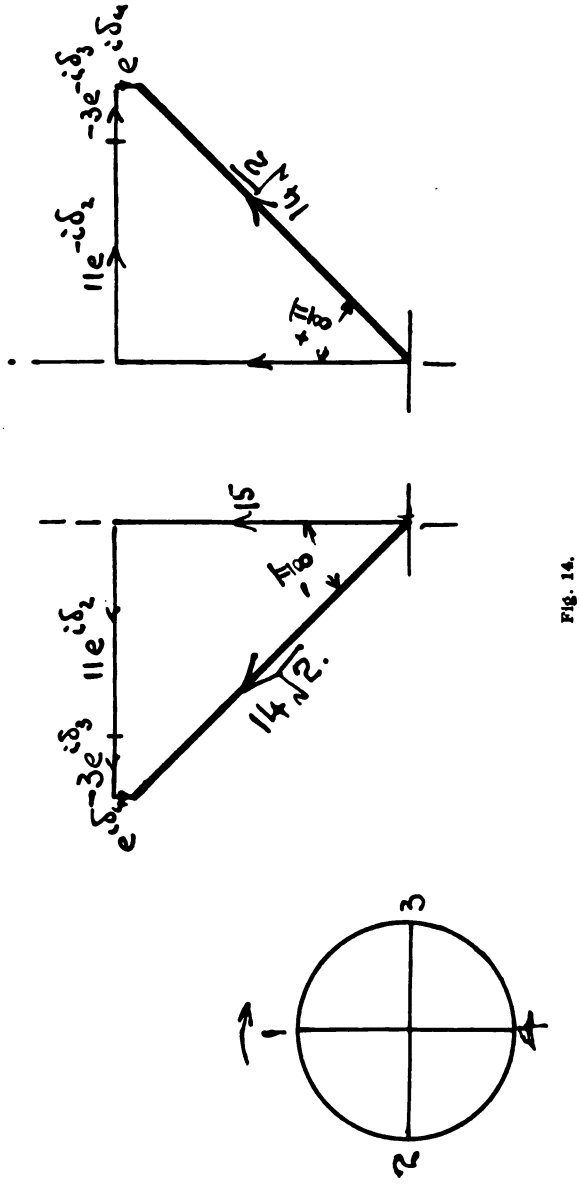

Fig. 14.

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justification for the separate treatment of the component orders in this case, it represents an alternative method to that usually adopted, and may possess some advantages. An elliptic form of variation of the reaction is naturally obtained for each order, and the proper summation of the several ellipses would establish the full polar diagram of reaction.

Referring again to the four span arrangement of Fig. 13, the reaction of, say, bearing III would be expressed by

$$R_{III} = \tfrac{1}{2}\bar{P}_3 - \frac{M_{II} - M_{III}}{l} + \tfrac{1}{2}\bar{P}_4 + \frac{M_{III} - M_{IV}}{l} \quad \cdot \quad (39)$$

from which the form for any bearing is obvious.

On substitution of the M values, there follow

$$\left.\begin{aligned} R_0 &= \tfrac{1}{448}(\ 179\bar{P}_1 - 33\bar{P}_2 + 9\bar{P}_3 - 3\bar{P}_4) \\ R_I &= \tfrac{1}{448}(\ 326\bar{P}_1 + 254\bar{P}_2 - 54\bar{P}_3 - 6\bar{P}_4) \\ R_{II} &= \tfrac{1}{448}(-72P_1 + 272\bar{P}_2 + 272\bar{P}_3 - 24\bar{P}_4) \\ R_{IV} &= \tfrac{1}{448}(\ 18P_1 - 54\bar{P}_2 + 254\bar{P}_3 + 302\bar{P}_4) \\ R_V &= \tfrac{1}{448}(-\ 3\bar{P}_1 + 9\bar{P}_2 - 33\bar{P}_3 + 179\bar{P}_4) \end{aligned}\right\} \quad \cdot \quad (40)$$

When the crank angles are introduced in the usual way and the summation of the ensuing series effected, by the process already illustrated in the case of the moments, any bearing reaction clearly reduces to the standard form

$$\bar{BR}_n = (Re^{i\alpha})_n e^{in\theta t} + (Se^{i\beta})_n e^{-in\theta t} \quad \cdot \quad \cdot \quad (41)$$

and is interpreted in the usual fashion.

It will be understood that the group equations for moments, (36), and reactions, (40), are fixed by the shaft scheme, and, once determined, apply to all orders. The reduction of the orders to standard form is then quite readily made, and, in particular, in the case of unbalanced force orders, only involves numerical, in place of graphical, summation, since then all the vectors are in one line.

The consideration that has been given to shaft effects has been mainly for the purpose of demonstrating that the analysis of shaft and frame may follow quite similar lines. The endeavour to achieve a comprehensive view of the subject necessarily compels a somewhat cursory treatment of the more

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intricate sections. But the whole subject is very extensive, and the main function of the present discussion of it has been to emphasise the fact that, whether dealing with a single action in a simple line of engine parts, a combined action in an engine element, an effect in a group of elements, total body forces, torques, or couples, or internal stresses due to these, the one general conception serves, and the one general method resolves, all of them.

Discussion.

Mr. JOHN S. BROWN, M.B.E. (Member): While this paper deals with a subject which is of increasing importance to the internal-combustion engine industry, it is not agreed that this is its sole field of application. The problems of engine vibrations have all come under notice in reciprocating steam-engine plants, and such examples could be quoted from the technical press of Germany, France, and America. But the internal-combustion engine has brought heavier reciprocating masses and also higher piston speeds, with the effect that the minor inconveniences in the odd examples of the past now become so accentuated that their intrusion may involve distinctly serious consequences. The effects are not confined to the engine structure, or its working parts, but also appear in the hull of the ship, or other situation, in which the power plant may be located. For a complete examination of the effects of these out-of-balance forces, it is necessary to review the design of the whole structure considered as a unit.

It is clear, however, that Prof. Kerr has not attempted to carry the matter up to this final point, but is satisfied to have demonstrated the range of the forces and couples which are originated by the working of the engine, and proceeds to ask for examples from practical experience, so that a position may be reached where the prominent factors can be separated from those of minor consequence. The effects under consideration are so involved that the course indicated is the only direct method of arriving at practical results, and in the mean-

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Mr. John S. Brown, M.B.E.
time, the only general observation which can be offered is that the majority of the factors will probably disappear under this method of treatment.

This paper also sets out to show that the same general method may be applied to all cases; but this has to be carefully interpreted, as there is no real uniformity in the indicator diagrams from all internal-combustion engines, and still wider variations occur when steam engines are also included. That is to say, the examination of a given case at the design stage must be made from a close approximation to the anticipated form of indicator card. Very probably it is just this fact which prevents concise conclusions from being presented in the paper now before us. I cannot, however, help suggesting that there is available a representative range of marine oil-engine designs in the five reports of the Marine Oil-Engine Trials Committee, and most of the factors could be evaluated by submitting them to a detailed analysis.

A few examples may be passed under review where torsional oscillations have been met with, and where the point for special notice is that the critical conditions arose in quite an insidious manner, through some minor alteration to a design which previous experience had shown to be satisfactory. There is the case of a marine oil-engine of established design which was constructed with one extra cylinder to give increased power, but on going into service it proceeded to throw off its propeller blades after three weeks' duty, and has confirmed itself in this attitude by repeating the process with three successive propellers. Again, an entirely successful four-cylinder engine for land duty was developed into an eight-cylinder engine of twice the power, with the result that both the first and second degree criticals were brought into close vicinity to the running speed, and it will take quite serious alterations to displace these criticals to give a satisfactory margin. In another case, a six-cylinder engine is to-day being provided with a type of flywheel at the centre of the engine length, in order to make it possible to run at what was intended to be the designed speed. In each of these instances the conditions could have been pre-

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dicted from the drawings, and Prof. Kerr's plea is that the designer has failed in his duty when the important consequences just illustrated are left to chance.

Mr. JAMES THOMSON (Associate Member): We are all indebted to Prof. Kerr for his very complete exposition of the forces obtaining in the moving parts of a reciprocating engine, as the passenger in the modern liner is very particular in the matter of comfort, and prefers to travel in those vessels where, other things being equal, there is least vibration. The steam turbine demonstrated that a ship at sea, apart from weather, could be as free from vibration as an hotel, but, unfortunately, the balanced internal-combustion turbine is not yet reliable, and in those cases where the internal-combustion engine is the most economical proposition, we are forced to use the reciprocating engine, and the problem of balancing the inertia forces is of great importance. Prof. Kerr deals with the theoretical aspect so thoroughly that it is beyond criticism, but perhaps a few remarks on the practical difficulties of balancing marine engines may not be out of place.

In comparison with the reciprocating steam-engine, the Diesel engine has much heavier moving parts usually running at higher revolutions and causing greater inertia forces. In addition, the Diesel engine is longer, involving much larger couples, but this disadvantage is counteracted by a greater number of moving lines, which may be arranged to balance each other more or less. Prof. Kerr correctly states that the modern designer rarely considers the Fourier series beyond the second term. The first order is of supreme importance, and must be satisfied as completely as possible, and if there is any choice between various arrangements which fulfil this condition, that arrangement should be selected which will make the best of the second order, which is of less moment. The third and succeeding orders have very little effect, and probably it would be necessary to correct them by an arrangement similar to the Lanchester device, as a modification of the arrangement of cranks would probably upset the primary or secondary balance,

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Mr. James Thomson.
and cause a very much greater disturbance than that due to the third and succeeding orders.

A much more important consideration in the design of large engines is the stiffness of the engine structure. In order that a perfectly balanced multiple-engine may not transmit vibrations to the supporting structure, be it ship or otherwise, it is obviously necessary that the whole framework should be sufficiently rigid to prevent deflection under the varying distribution of the various forces in each line. This is practicable in small units where the soleplate and entablature are often a single casting, but as the size increases the difficulties become greater, and in very large engines almost insurmountable. It is possible to take two right and left hand three-crank engines, each very much out of balance as to couples, and bolt them together in line and produce theoretically a perfectly balanced six-crank engine, but practically the success of the arrangement would depend on the rigidity of the structure joining the engines, and if the strength and stiffness of the soleplate, etc., should be insufficient for the forces caused by the unbalanced couples on either side, these forces would act on the ship's structure forming the engine seating, from which vibrations would be transmitted to other parts of the vessel.

It may even be necessary to sacrifice the apparent perfection of balance of the engine as a single unit, in order to get a better balance in the sections on either side of the middle, and thus limit the residuary forces from these sections which must be transmitted through the framing, so as to suit the strength and stiffness of the structure.

In large marine engines, while it is necessary to make the engine structure rigid on account of balancing, the seating upon which the engine rests is part of the hull, and is subject to the hogging and sagging of the vessel in a sea-way, so that if the engine is of great length it is necessary to provide for this deflection by dividing the engine longitudinally into stiff sections connected by a more or less flexible girder. If this arrangement requires to be adopted, it is very desirable that the balance of the moving lines in each section should be self-

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contained as far as possible, so that the residuary unbalanced couples, which must be transmitted between the sections by means of the hull structure, will not cause vibration.

In a two-crank section the couples are obviously very large, and as the number of lines increases the couples decrease. At least five lines of moving parts are desirable to minimise the couples in one stiff section, and each section of a large engine, in which provision is made as above for the working of the ship, should also consist of five lines, and even then slight vibration may occur. In the ideal engine, the soleplate and column structure should form a deep continuous girder of great strength and rigidity, but marine requirements sometimes prevent this being realised. This consideration suggests that the reciprocating engine is not a suitable type for very large machines, and the reported failure of the soleplates of large engines also suggests that due consideration has not been given to these problems.

Prof. Kerr's remarks about the guide reactions also point to the necessity of torsional stiffness in the structure of the engine, and in multiple-screw vessels the various engines are usually connected by athwartship ties as high as possible, in order to stiffen the general structure and to an uncertain extent balance one engine against the other.

With regard to the harmonic balancer, two four-cylinder four-cycle Diesel engines, with cranks at 180 degrees for driving electric generators, were recently fitted in a large passenger liner, and considerable vibration, due to the secondary forces, appeared in various parts of the vessel. We requested the makers to fit an harmonic balancer of the Lanchester type, and the vibration disappeared.

Dr. R. M. Brown (Member): The effects of vibrations in engines and structures fall, roughly, into two classes:—(1) Cases in which the inertia stresses become dangerous to some portion of the structure, and (2) cases in which the vibrations cause discomfort or are otherwise objectionable without being directly dangerous. In (1), the problem is

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Dr. R. M. Brown.
largely one of the endurance of metals under fluctuating stress, and if the stress variations, due to any given system of masses and accelerations, be investigated, the necessary degree of balance to keep inertia stresses within safe limits can be explored mathematically with reasonable success, so far as direct effects are concerned. This gives the most definite aspect of the vibration problem. The more indefinite aspect arises when failure occurs in some portion of the supporting or adjoining structure, due to resonance, and a solution of this problem involves a mathematical investigation of the natural period of vibration of the structure. The whole investigation is, therefore, much more complex, and no very general treatment is possible. The second class of phenomena are even more difficult to investigate directly, owing to the difficulty of defining when a vibration becomes objectionable.

In both cases, the obvious treatment is to balance, as completely as may be necessary, the motor, or the source of disturbance; then sympathetic vibrations in the supporting structure can be dealt with by making such modifications as may be necessary to change sufficiently the natural period of vibration. The crux of the problem is the defining of the words "to balance, as completely as may be necessary," and this cannot be done by mathematics, but only by the co-operation of designers and constructors.

Prof. Kerr's paper shows, in a very able manner, how the out-of-balance effects can be calculated, and, therefore, modified, but the paper does not, and cannot, indicate the magnitude of an out-of-balance effect which just produces disturbances which are inconvenient or unpleasant. This aspect can only be adequately dealt with by manufacturers of engines, and if they do not co-operate by bringing forward some data, the value of Prof. Kerr's paper to engineers in general will be greatly diminished, although it will remain of great value to those manufacturers and designers who desire to investigate balance systematically, and who tabulate results for their own information.

If manufacturers would state frankly the order of the out-

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of-balance forces and couples in their engines and the nature of the resulting vibrations, such pooling of information would lead to rapid progress in the art of eliminating unpleasant and dangerous effects; but perhaps it is too much to expect that a firm of manufacturers would confess to any out-of-balance effects whatsoever in their machines, and the fear of helping competitors by publishing results is always greater than the expectation of deriving benefits by a pooling of information.

Mr. JAMES F. SHANNON, A.R.T.C.: Prof. Kerr has presented this subject in its entirety, and the method of examination

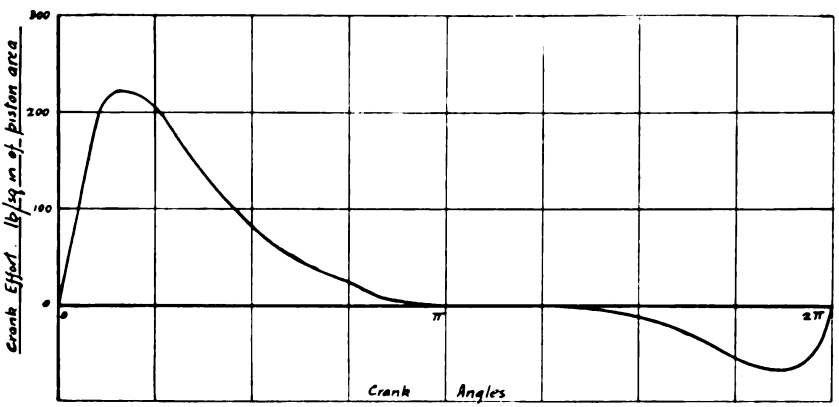

Fig. 15.—Indicator Card on Crank Angle Base.

and reduction of widely different actions should prove of great service in the elucidation of the causes giving rise to troublesome engine drives. In connection with shaft effects, the total torque has been clearly shown, with symmetrical crank schemes, to be formed by the summation of the unbalanced torque orders. A full appreciation of this fact should be of considerable value in the early stages of multiple-engine design, since the total crank effort can be obtained once the crank-connecting-rod ratio "c" and the indicator card have been assumed. For example, the unit crank-effort diagram

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Mr. James F. Shannon, A.R.T.C.

shown in Fig. 15 has been derived from a six-cylinder, two-stroke engine card having a "c" ratio of 0·254. Now, since the unbalanced torque orders for the complete engine are 0, 6, 12, - - -, the inertia effects are not included, so these unbalanced orders may be calculated directly from Fig. 15, and in this case are found to be $33{\cdot}5 - 8{\cdot}15 \cos (6\theta + 36^\circ - 12')$ $- 1{\cdot}43 \cos (12\theta - 45^\circ) + - - - -$. Hence for the complete engine the total crank effort is given by $6[33{\cdot}5 - 8{\cdot}15 \cos (6\theta + 36^\circ - 12')$ $- 1{\cdot}43 \cos (12\theta - 45^\circ) - - - - - -]$. This summation is shown in

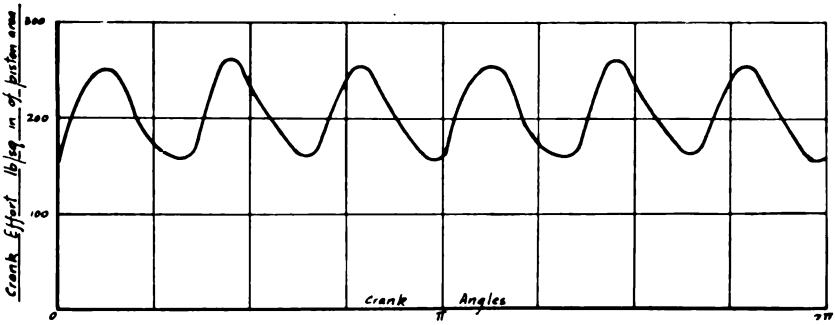

Fig. 16.—Total Crank Effort.

Fig. 16, and it coincides with the actual torque curve, built up in the usual way.

The main point to be appreciated here is that, with symmetrical crank arrangements, the relative values of the unbalanced orders depend entirely on the engine dimension "c" and on the indicator card, varying according to the power given out. The effect of this variation will show mainly in a corresponding change of amplitude. For final design purposes, the effect of compressors and unequal crank spacing can only be determined by a full analysis of the total torque curve, which will include the effects of inertia.

Mr. W. H. Riddlesworth, M.Sc., M.Eng. (Member of Council): Prof. Kerr presents a subject of great and increasing importance in a very comprehensive and attractive fashion.

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He, however, fails to recognise that very many of the people who ought to be able to take advantage of his work are repelled at the outset by the unfamiliar mathematical tools he uses, and while it may be true that the results are there for use by any who are unable to follow the process by which they are derived, yet it is most desirable that the method of derivation should be fully understood. It appears to me that a mathematical process which enables Prof Kerr to obtain and to group together so many complicated actions is well worth knowing, and I ask him to add to his paper some preliminary explanation of the *modus operandi* by which he obtains his results.

Examples of unfamiliar methods are not far to seek, but the following two will serve as samples of the sort of thing that requires explanation:—

1. "Now, since $e^{i n\theta}$ is merely the algebraic notation for a vector set at the angle $n\theta$"—p. 713.
2. "Now, the symbol i stands for the so-called imaginary $\sqrt{-1}$, but from the vector point of view it is merely a special way of stating $e^{i\frac{\pi}{2}}$, and, therefore, it represents a unit vector set at 90 degrees to the standard reference direction"—p. 713.

I am sure that Prof. Kerr is able to give a fairly brief and concise explanation of the methods he has adopted, and am convinced that it will add greatly to the value of his paper as well as provide others, like myself, unfamiliar with the method, with a new tool or key wherewith to attack other problems. It might also be worth while indicating clearly when, in the text, he passes over from ordinary algebraic notation to the less familiar vectorial system.

Mr. Alan E. L. Chorlton, C.B.E.: The question of vibration in one form or another has become so highly important in all forms of machinery, apart from prime movers, which are principally dealt with in this paper, that the more investiga-

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Mr. Alan E. L. Chorlton, C.B.E.

tion we have of the governing factors and the proposals for their control, the better will engineers and designers be placed to meet developments in various forms. I welcome, therefore, very much indeed the paper by Prof. Kerr, and must congratulate him on the most detailed and excellent way he has tackled the problem, so far as he has gone. It is to be hoped that he will find time later on to extend this work, dealing more particularly with various vibrations and their resonant periods in engines.

In the past few years, I have been responsible for the development of a fast-running Diesel type of oil engine, which has throughout compelled the closest attention to vibration in the running parts. Prof. Kerr mentions torsional vibrations of the crankshaft, and in such types of engine these vibrations form one of the first considerations of a new design that have to be safeguarded. The points in the paper dealing with the question of balancing and their reactive effects are very valuable in connection with the disturbing influences, particularly in installations on board ship, and their investigation by Prof. Kerr is of particular interest to engineers from the sound scientific method of investigation used.

The splitting up of disturbing forces into prime components and dealing with each of these in a similar manner, enables the relative importance of the several sources of disturbance to be appreciated both as whole and as critical orders, but from the equations given it is very difficult for a designer to gauge the relative values except by working out complete examples. A point which causes practice to depart from rigid theory is brought about by the elastic deformation of the main body of the engine. It is admitted that it becomes a very difficult matter to allow for this mathematically, but its relative effect on the different prime forces must be considered.

Not only is crankshaft design concerned in the consideration, but the influence of different engine layouts on crankcase stiffness, particularly longitudinal, and hence, on load distribution on crankcase and crankshaft, should be assessed in deciding on the type of engine or case to employ in an

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application. Against the advantages of assuming a perfectly rigid structure must be placed the "softening" effect of using an elastic one in which peak loads, especially from gas pressures, would be reduced.

Again, I might repeat, it is the resonant periods of vibration that require attention, and a sense of damping out of criticals in all advanced forms of engine design must be developed by designers.

Mr. H. F. P. Purday: Prof. Kerr has effected a remarkable unification of several problems in the mechanics of reciprocating engines by the uniform procedure of development in Fourier series and expression in terms of exponentials. In vibration problems, whether torsional or transverse, development in Fourier series is indispensable, and leads to an easy and rapid evaluation of vibration stresses at the critical speeds, but Prof. Kerr has extended the use of the method to a class of problems in which the advantages of the method are not so widely recognised. By this method it is possible to forecast which terms will cancel out in the result, with a gain in brevity and accuracy in comparison with methods in more common use.

On page 743, it is stated that ranges and rates of alternation of shaft stresses are obscured by the usual methods of calculation. In Dr. Milton's paper, read before the Institution of Naval Architects in 1911, a method of plotting shaft torques at any section on a time base is described, and this reveals both the range and rate of alternation of stress if carried out in full. The method has been very widely used. The assumption is made that the torque at any journal is the sum of the torques due to all the cranks "forward" of that journal. This is approximately true if there is a fly-wheel "aft" having a moment of inertia large in comparison with that of the crank masses, and leaving resonance effects out of account. In an arbitrary distribution of mass moment of inertia along the shaft, the torque at any journal is influenced by the torque applied at every crank, and the method is no longer correct. Prof. Kerr's treatment of shaft torques seems to be open to the same

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Mr. H. F. P. Purday.

criticism. A simple method of applying an approximate correction has been given by me elsewhere.* In strictness, the determination of shaft torques involves the solution of the equations of motion of all the crankshaft masses. Such a process would be very lengthy, and in practice it seems preferable to treat resonance effects separately, and to superimpose the results on the shaft torques calculated without regard to resonance.

In the calculation of resonance torques at the critical speeds, the appropriate vector quantities are the applied harmonic torques of any given order at the several cranks, multiplied by the displacements at the corresponding points during a free vibration. Thus the process conforms to the general procedure outlined in the paper.

Prof. Kerr's paper is very suggestive, and can hardly fail to have a beneficial influence on the methods used in the problems referred to.

Prof. Kerr: Mr. J. S. Brown quite rightly mentions that vibration difficulties are not confined to internal-combustion engines. They have been experienced in steam engines; and some attention was certainly given to the subject before the oil engine types had grown beyond infancy. In fact, the Gümbel method of examining torsional oscillations had its origin in an analytical study of such happenings in steam drives. But what was a rather infrequent trouble in the older system has shown itself a common occurrence in the new; and, in contrast with the keen attention compulsorily directed to the phenomena now, the studies of the subject in the earlier period were rather vague and superficial. The mode of action, the speeds, and the masses of the oil engine all combine to make the modern problem much more acute, and compel a more serious and more profound study of causes and prevention.

It appears that Mr. Brown considers that the variations in indicator diagrams "prevent concise conclusions from being presented in the paper." This is not the case, however. To

* "Diesel Engine Design," 3rd Ed., Chap. XV. Constable.

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the methods of analysis differences in the diagrams are merely akin to differences in the masses or speeds; they are characteristics of the individual engine. Generality of treatment resides in the fact that the same kind of relations apply throughout. The paper only casually refers to the indicator diagram. It is presumed that the reduction to Fourier coefficients can be carried out by standard methods. Several writers have endeavoured to provide means of overcoming the numerical labours by establishing suitable coefficients for general use. Thus, Prof. Lewis gives the harmonic coefficients of torque for typical Diesel cards varying with mean effective-pressure; while a German authority, I think, has given an elaborate set of coefficients based on theoretical cards. Mr. Brown apparently suggests that the five engines tested by the Marine Oil-Engine Trials Committee could provide all the necessary data here. They certainly would allow of useful deductions regarding the cards, but the point I have endeavoured to make is that the arithmetical labours are not profitable unless the results can be correlated with observations of exceptional dynamical features in the running of the engine. I do not think that the Committee's reports disclose any points of the kind.

Mr. Thomson, in a most interesting fashion, discloses the attitude of mind of the designer of high-power marine engines, and emphasises the practical difficulties of this important line. When he specifies, as an essential procedure, the balancing of the first order effects and the selection of that arrangement which minimises the secondary, he is presumably concerned with certain types only, since there are others in which both orders are balanced. Further, it must again be stated that the negligibility of orders beyond the second only applies to inertia forces; it does not apply to torques. In raising the question of the stiffness of the engine structure, Mr. Thomson introduces vital issues about which a great deal could be said, but little of it could really be definite because of the lack of quantitative data. Personal opinion appears to be the main guide in these matters, and the more comprehensive the survey of frame

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designs in large engines the more certainly does it appear that the opinions are rather variable. The emphasis which Mr. Thomson places upon this matter adds weight to the assertion in the paper that a complete view of balance must include a recognition of the elastic problems as well as the dynamical ones. It is clear that Mr. Thomson views the distributed force systems of large engines with dread; and his remarks on soleplate failures and on the necessary sacrifice of some degree of balance in the unit structures of a multiple set, in order to minimise the actions transmitted between them, demonstrate at once his reasons for doubt and the design point of view to which he has been led. There must be a necessary rigidity, and there should be a criterion of it. The adequate study of the data from the engines that break their soleplates would help to establish it and guide design to the soundest judgments. In the absence of such data I am not competent to express an opinion, and designers must be left to express theirs in the monstrous iron structures for which they are responsible. Mr. Thomson makes out that the structural stiffness is a more important question than balance; but this tends to confuse cause and effect somewhat, and I feel that the faults of the frame are occasionally due to a lack of appreciation of the full variety of out-of-balance effects, and particularly those due to torques. It is remarked that athwartship ties between frames are sometimes employed, and I would direct attention to Mr. Thomson's rather deliberate use of the word "uncertain" here. It is easy to conceive conditions in which there is uncertainty.

Mr. Thomson introduces an especially interesting point in the matter of the effect of hull distortion on long engine frames, and he develops a valuable conception of how these long engines should be built in separate elements connected by a "more or less flexible girder." Hull distortion is, of course, extraneous to the problem of engine balance, but that it introduces equally important consequences no one can doubt. The idea appears to be that each section should contain a sufficiency of lines to keep the unbalanced effects to a low value; but while

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I am not desirous of opposing Mr. Thomson's opinion in such a matter, I would submit that the introduction of a degree of flexibility in the connecting element, with the natural consequence of increasing the degrees of freedom of the system, calls for a higher standard of balancing in the individual engine sets than is allowable in a continuous frame. I think this aspect requires some consideration, but it is the only criticism I have to offer of a valuable idea.

Dr. Brown's contribution provides an interesting commentary on the general point of view I have taken up. He recognises the necessity for the co-operation of designers and constructors in this whole subject, but in his anxiety to emphasise this he does, I think, rather unduly depress the relative importance of the factor of analysis. It is barely right to say "this cannot be done by mathematics but only by co-operation . . .''; it would be more correct to state "this can be done by analysis in the event of co-operation . . .'' In complex design work responsible people are generally sceptical of the value of analysis. This may be justified by certain experience, but it is really experience of analytical work which has *not* been adequately guided by observation. Such a faulty process is quite inferior to intuition; but in all design developments in the complex practice of to-day a stage is always reached when reasonable analysis, although admittedly imperfect, becomes vastly superior to mere intuition. I observe that Dr. Brown—for stated reasons—is afraid that it is too much to expect the pooling of information in subjects of this kind; and while he is probably right, we may be permitted to regret it.

I am grateful to Mr. Shannon for the labour he has expended on the subject of engine torques, and a perusal of his remarks and figures should render the essential harmonic coefficients of the complete torque diagram quite clear. The point which he illustrates lies in the allowable neglect of inertia terms in the addition, and the readiness with which the final result may be arrived at should be noticed. In view of the procedure frequently followed in design offices, the demonstration should be especially useful. When Mr. Shannon refers to the inclu-

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sion of the compressors, it should be understood that the inertia effects are those of the compressors only.

Mr. Riddlesworth is the only commentator who makes definite reference to the theoretical procedure in the paper. He does that for the purpose of requesting further light on the use of the "imaginary quantities." I am glad he has raised this point, although, of course, it will be understood that this is hardly the place to enter into any full account of the matter. But the mechanical engineer in general has rather completely ignored a process of analysis which has rendered great service to the electrical branch of engineering. The electrical engineer uses "j" instead of "i"—to avoid confusion with symbols for current—but the egotistic "i" is alone adequate to express the virtues of this famous quantity. I should have liked to believe that the uses I have made of the method do convey some idea of these virtues; but, judging from Mr. Riddlesworth's remarks, I gather that they are somewhat obscure, and I humbly accept of Mr. Riddlesworth's reservice of my own words as demonstrating this. It is hardly a part of the duty of a paper on the balance of engines to provide a dissertation on the mathematical operations it utilises, but perhaps the following line of approach may be found useful as indicating the essential simplicity of the idea.

A quantity $(+r)$ is ordinarily represented by a length marked off to the right—the reference direction. The quantity $(+r)\times(-1)=(-r)$ is the same length set off to the left; and $(+r)\times(-1)^2=(+r)$ is again to the right. So that multiplication by (-1) turns the line through the angle π, while multiplication by $(-1)^2$ turns it through 2π. Employing the usual idea of an index, $(-1)^n$ will turn the line through $n\pi$; and so $(-1)^{\frac{\theta}{\pi}}$ is simply an operator which means the rotation of the vector through the angle θ. If we want, in elementary mechanics, to express the fact that a vector of length m acts at angle θ, we frequently write m, as a shorthand expression; but a correct statement for the same thing is now seen to be $m(-1)^{\frac{\theta}{\pi}}$. If $\theta=\frac{\pi}{2}$, the operator is $(-1)^{\frac{1}{2}}$—the

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square root of (-1)—meaning a direction perpendicular to the reference. This $(-1)^{\frac{1}{2}}$ is given the special symbol i.

Now the line r, set off at θ, may be taken as the hypotenuse of a right-angled triangle whose one side is a, set off along the reference direction, and whose other side is b, at right angles thereto, Fig. 17. Then r at θ, or $r(-1)^{\frac{\theta}{\pi}}$, is the same thing, vectorially, as $a+ib$. It is a vector along the direction θ, or a complex quantity, depending on whether it is viewed as a line or an algebraic expression. It is clear from Fig. 17 that

$$a+ib=r(\cos\theta+i\sin\theta),$$

so that $(\cos\theta+i\sin\theta)$ is equivalent to $(-1)^{\frac{\theta}{\pi}}$, and, therefore,

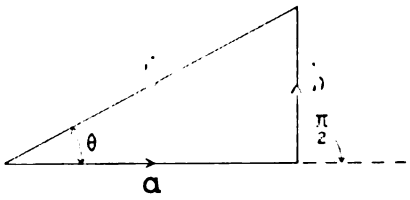

Fig. 17.

acts as a rotational operator. When $\cos\theta$ and $i\sin\theta$ are expanded in series form, we get

$$(\cos\theta+i\sin\theta)=1-\frac{\theta^2}{L^2}+\frac{\theta^4}{L^4}+i\left(\theta-\frac{\theta^3}{L^3}+\frac{\theta^5}{L^5}+\cdots\right)$$

$$=1+i\theta-\frac{\theta^2}{L^2}-i\frac{\theta^3}{L^3}\cdots$$

and this is simply the series for $e^{i\theta}$, i being used as an ordinary algebraic quantity throughout. By this brief development, we find that

$$r_\theta\ ;\ r(-1)^{\frac{\theta}{\pi}}\ ;\ a+ib\ ;\ r(\cos\theta+i\sin\theta)\ ;\ r.e^{i\theta}$$

all mean exactly the same thing—a vector of length r set off at angle θ to the reference. Since the development is by algebraic methods, the developed forms are amenable to the laws of algebra, and we obtain a notation which deals with directed vector quantities in a straightforward manner. Thus,

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if a periodic force, such as an engine inertia force, given by

$$F_1(\cos \phi_1 + c \cos 2\phi_1),$$

acts along a line at 45 degrees to the reference, together with

$$F_2(\cos \phi_2 + c \cos 2\phi_2)$$

acting along another line at 120 degrees to the reference, the total effect is at once obtained by writing

$$F_1(\cos \phi_1 + c \cos 2\phi_1)e^{\frac{\pi}{4}} + F_2(\cos \phi_2 + c \cos 2\phi_2)e^{\frac{2\pi}{3}}.$$

The normal attempt to conceive the combined action would involve a vector sum of instantaneous values; but the expression avoids the thought and labours of such a process, and provides an accurate and full description capable of "blind" treatment by algebraic methods.

The mathematician complicates the matter very seriously by employing any of the different forms and a rich variety of methods; but if the simple idea is comprehended and the fundamental sameness of the different forms appreciated, a wide range of mathematical processes becomes intelligible, and such apparently abstract conceptions as "De Moivre's Theorem" and the "n roots of unity" are easily understood. In general the work embodied in the paper does not contain anything beyond what has been explained above, but the detail steps are in most cases omitted. The work of the engineer does not require the deeper applications of the process, but in all vibration and allied problems the notation is of great power and value.

I am pleased to have Mr. Purday's support of the general method of attack which I have used, and consider that the expressed agreement of an author well known for his capable treatment of Diesel-engine design problems is a justification of the claims made on behalf of the method Mr. Purday refers to, and criticises, Dr. Milton's method for the addition of shaft torques—with which I am not familiar—and considers the summation I have made open to the same criticism. I confess that I was not attempting more than a simple review of this

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matter, and was quite aware that there were finer issues involved in the detail study of shaft stresses, just as there would be in the fuller examination of frame stresses. But so far as shaft stress effects are concerned, the finer matters arise out of damping influences and the significance of amplification factors—points on which I seek the guidance of genuine and observed fact. I am pleased to have the reference to Mr. Purday's approximate method—at the moment I have not access to it—but I suppose that what is meant by the statement regarding the "arbitrary distribution of mass moment of inertia along the shaft" is the angular inertia consequences of the combined reciprocating and rotating parts. It should hardly be necessary to include these unless we are expected to change the various series to cover for cyclic irregularities in speed. Those who have reached the stage of introducing such refinements must possess the kind of information I am still in search of, or otherwise the refinements are hardly justified. Mr. Purday refers to the superposition of the resonance and shaft torque effects. I submit that one main point at issue lies in the true elucidation of the former. In his final reference to appropriate *vector* quantities, Mr. Purday defines these as harmonic torques multiplied by displacements. The statement may suffer from being too concise, but these products appear to me to be work quantities.

Mr. Chorlton's responsible association with an advanced type of high-speed Diesel engine is well known, and his emphasis on the problems of vibration should demonstrate very clearly the urgency of these questions. Mr. Chorlton's entire contribution; Mr. J. S. Brown's interesting citation of actual cases of torsional vibrations; Mr. Thomson's case of the engines that required the Lanchester balancers; and the occasional remarks of others, all bear out the main contention of the paper that this subject requires special, and immediate, study. Mr. Chorlton expresses the opinion that I have taken the subject a certain distance, and desires that it may be extended later. I presume that all responsible people in this line are keenly anxious to have the questions of vibration freely ventilated;

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but I am afraid, judging from this discussion, that the real point is not yet clearly seen. I found myself confined to general analysis because of the absence of definite information, and I regret that those who are clearly able to bring forward the true details have not done so. In fact, while the tone of the discussion is undoubtedly that of faint regret that the paper deals with general matters, I find it necessary to inform my critics that they are even more general in their references to the subject than I have been. I am sure it will be agreed that the subject of ship vibrations will require to receive careful attention and investigation in the near future, but I am equally sure that a satisfactory treatment will necessitate the open discussion of the actually observed effects of engine actions.

I am grateful to the contributors to the discussion for the many interesting points they have advanced, and for the various remarks they have made regarding the work I have attempted; but more definite information must be awaited before the subject can be readily or usefully developed along the lines of the real difficulties.

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STUDENTS' SECTION.

Abstracts of Papers Read.

CONDENSERS, AIR PUMPS, AND EJECTORS.

By F. J. Maunder, B.Sc.,
Student of the Institution.

4th November, 1927.

Condensers.

The function of a condenser is two-fold. Firstly, to remove from an engine, as far as possible, the effect of atmospheric pressure, by receiving the exhaust steam and condensing it to water, thus creating a partial vacuum; and secondly, to enable steam in its last phase to be expanded to a lower pressure than can profitably be done when the steam exhausts to atmosphere. In a non-condensing engine it is possible, by exhausting into a L.P. turbine, to add 75 per cent. to the power obtained from the steam, even after allowing for the power required for condenser auxiliaries.

Two laws control the design of condensers.

1. That in any mixture of gases and vapours each constituent exerts its own pressure independently, and the extent of this pressure is the same as the vapour would exert, if present in any otherwise vacuous space.
2. The number of molecules of a given vapour which can be contained in a given space is the same, whether

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the space contains the vapour alone or other gases or vapours in addition.

Exhaust steam does not strictly conform to particulars given in steam tables, as it contains a certain amount of air. The temperature and pressure of this mixture follow Dalton's law. In most problems the temperature and absolute pressure of the air and vapour leaving the condenser are known, and with the aid of Charles' law the specific volume of the air at the temperature at which it leaves the condenser can be found. This law is expressed by the symbols $\frac{PV}{T} = \text{Constant}$, where P, V, and T represent pressure, volume, and temperature respectively. An empirical formula, drawn up by the British Electrical and Allied Manufacturers' Association to facilitate design, gives the mass of air to be withdrawn from the condenser as $\frac{\cdot 5W}{1{,}000} + 3$ lbs. per hour, where W equals the total weight of steam condensed per hour.

In a condenser, the heat from the condensing steam on the outside is transferred to the water circulating on the inside of the tubes. The flow of heat across a metal wall or partition varies directly as the temperature difference between one side and the other, and inversely as the resistance to heat flow. The heat flow h is usually expressed as

$$h = \frac{\text{Difference in temperature}}{\text{Resistance}}.$$

The resistance comprises four components.

1. Resistance at the surface of the tube wall, which depends on the water velocity in the tube, the tube diameter, and the viscosity and density of the water passing through the tube.
2. Resistance across the tube wall, which depends on the thickness of the material from which the tube is

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made. A small deposit of scale on the tube surface is sufficient to increase this value considerably, as it is a bad conductor of heat.

3. Resistance due to the water film of condensed steam on the outside of the tube, which depends on the viscosity and density of the water film adhering to the outside of the tube.
4. Resistance due to the air blanket surrounding the tube, which depends on the quantity of air in the condenser, and is by far the greatest.

The values of these various resistances may be ascertained by the aid of equations or graphs evolved from experimental data, from which the condensation rate may be determined. Supposing that the vacuum required, the quantity of steam to be handled, and the average temperature of the water to be circulated for cooling purposes, are known. If the condenser is for a land installation, then it may be advantageous to install one with a small temperature difference between the entering steam and the outgoing water, which would mean a large condenser with high charges for water cooling; but the reduced consumption on the turbine due to the high vacuum obtained usually warrants the increased cost. On the other hand, where space is valuable, as on shipboard, a smaller condenser is usually installed, not so much on account of the space occupied, but because of the large L.P. turbine which would otherwise be necessary.

Many condensers are designed to give an approximate constant velocity to the steam in its passage through the condenser, so that the lower tubes are steam swept, in order to prevent air blankets forming on the tubes and retarding the rate of condensation. To secure this, some condensers are made pear-shaped, as the steam diminishes in volume as it condenses.

It is necessary to conserve all the heat possible, so that the condensate may leave the condenser at the highest possible temperature, and this feature is met in the Regenerative Condenser in which the incoming steam can penetrate to the

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bottom, and thereby reheat the condensate to approximately the same temperature.

In the Mirrlees-Delas-Ginabat condenser, which is suitable for land or marine purposes, steam entering from the top impinges on the tubes at an acute angle, and the steam path through the tube is very short. The kinetic energy in the steam passing through the condenser reheats the condensate, and it is claimed for this condenser that a temperature, several degrees higher than the inlet temperature of the steam, is obtained in the removed condensate. The air-cooling chamber is an interesting feature of this condenser, the air having to pass over cold tubes at the cooling water inlet end, thus ensuring that its volume is reduced before passing to the air pump.

Corrosion in condenser tubes is a vexed question, and much time and money have been spent in seeking a solution to the trouble. That the cause of corrosion is not definitely known may be assumed from the widely divergent opinions advanced on the subject. It is averred that the present high velocities of circulating water cause turbulent flow through the tubes, and tend to liberate the oxygen in the water, leaving it free to attack the tubes, so that metallic oxides are formed; and that the presence of acids even in dilute quantities has a harmful and thinning effect on the tubes themselves. Experiments have shown that hydrochloric acid of a concentration of three parts by weight in 100,000 at ordinary temperature reduces brass tubes in six weeks from two to four per cent. in thickness. Pitting in brass tubes seems to be primarily due, with the use of sea water, to the formation of cupric chloride.

Undue stresses result in molecular friction, and consequent rapid corrosion has been attributed to excessive vibration. Dezincification, another source of trouble, characterised by disintegration of the brass tubes and repositioning of the copper, may be caused by the presence of acids or by the action of electrical currents passing from the tube to the circulating water when it contains certain chlorides.

Erosion, corrosion, pitting, etc., are nearly always from the

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inside or water side of the tubes. From recent investigations, it appears that a cure for most of these troubles is to be found in the use of tubes with a high nickel content, or Monel tubes.

Air Pumps.

With the old reciprocating engine, where a vacuum greater than 25 inches of mercury was rarely demanded, it was sufficient to extract the condensate, air, and vapour by a plunger pump of the three-valve type or Edwards' type, worked from the main engines. With the advent of the steam turbine higher vacua came into use, and it was found possible to utilise the power in the steam by expanding it in L.P. turbines to a pressure much below atmospheric. It is rarely, however, that a vacuum of 28·5 inches, corresponding to an absolute pressure of approximately $\frac{3}{4}$ lb. per square inch, is exceeded. With such a vacuum it is necessary to deal with the condensate and air and vapour separately, which is accomplished by the dual air pump, the dry chamber of which deals with the air and vapour, and the wet chamber with the condensate. By this independently-driven pump, a vacuum may be created in the condenser before starting up the main engines, thus minimising the temperature stresses by preventing excessive heating in the L.P. turbine and in the condenser.

With still higher vacua it was found necessary to make other arrangements for dealing with the increased volume of air and vapours, and Sir C. A. Parsons was the first to introduce a vacuum augmenter in the nature of a steam-jet ejector working in conjunction with an air pump.

Figures, given by Baumanns, show the decrease in the steam consumption of the main engines caused by a one-inch rise in vacuum:—

	Decrease in steam consumption. Per cent.
Between 26 and 27 inches of mercury -	4
,, 27 ,, 28 ,, ,, ,, -	5
,, 28 ,, 29 ,, ,, ,,	6

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Ejectors.

While air pumps proved suitable for the duties they were called upon to perform, the greater volumes of air, vapour, and non-condensable gases to be dealt with in high-vacuum condensers led to the introduction of the steam-ejector air pump, which in reality is an air compressor, the air being entrained by high-velocity steam jets. Steam is expanded through nozzles of the convergent-divergent type into the air-entraining compartment, where its static energy of pressure is converted into kinetic energy, thus causing the steam to leave the nozzles with a velocity of between 3,000 and 4,000 feet per second. The mixture of steam and air passes into a diffuser, where its velocity is gradually reduced until it is practically brought to rest with its pressure slightly above atmospheric, so that it can discharge to the atmosphere. The efficiency of an ejector is affected by the losses in the expansion nozzles, the losses due to impact during entrainment, and the losses in the diffuser. In the entraining space, the momentum of the steam and air before impact equals the momentum of the commingled steam and air after impact. With higher vacua, it is usual to carry out ejection in two or more compression stages. The ratio of the pressure of the air at the intake to the atmospheric pressure is the ratio of compression, which, with a vacuum of 29·5 inches, is approximately 1 : 6. Experiments on the subject show that the best rate of compression for a single-stage ejector is below 1 : 8. If the compression is performed in two stages, the intermediate absolute pressure for the overall compression ratio will be equal to 3·78 inches of mercury, the compression ratio of each stage will be 1 : 7·74, and the intermediate vacuum 26·13 inches. A two-stage air ejector will, therefore, operate quite stably when dealing with varying quantities of air, and easily maintain a vacuum of 29·5 inches when the conditions of temperature permit.

The majority of air ejectors on the market differ in the method adopted to secure stability. Le Blanc adopted the plan of admitting air into the throat of the second-stage

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diffuser, which varied the virtual ratio of throat area to exit area. Delaporte admitted the air between the stages of his ejector through a spring-loaded valve, which operated when the vacuum between the stages exceeded 26 inches, thus ensuring that the compression ratio of the second stage would never go beyond 1:8. The stability of this stage is thus maintained, and the first stage is able to maintain a high vacuum. In the Delas air ejector, stability is maintained by water-jacketing the diffuser nozzles. Other things being equal, the degree of vacuum depends on the distance between the throat of the diffuser and the end of the steam nozzle. By increasing this distance, the friction surface and weight of air withdrawn are increased, and a higher vacuum obtained. If the distance is too great, a drop in vacuum follows, and at the same time the air is increased in temperature in the convergent portion of the diffuser, resulting eventually in the failure of the extractor. The inventor was thus led to believe that this failure would be obviated if the convergent portion of the diffuser were kept cool. He, therefore, surrounded it with a water jacket, and found that, whereas the ejector broke down when the jacket was not in action, the vacuum was immediately restored when it was working.

The heat of the steam used in marine ejectors is lost in the cooling water, but against this there is the advantage that the ejector can maintain a vacuum in the condenser during manœuvring or a sudden shutting down of the main engines. In land installations the heat is recovered in the condensate cooling water, and passes to the hot well. The steam consumption ratio between the first and second stages is approximately 1:2·3, and the ejector has a steam consumption of about 560 lbs. per hour.

Three-stage air ejectors, having a much greater air-handling capacity than the two-stage types, have been recently introduced. The ratio of increase naturally varies with the quantity of air being handled, but at normal quantities it is roughly 3:2 on the same steam consumption.

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PRIME MOVERS.

By JAMES ORR, B.Sc.,
Student of the Institution.

16th March, 1928.

THE most important of recent developments in prime movers are the application of higher pressures in steam installations, chiefly in those of large power, and the use of increased powers in marine Diesel engines. The advantages to be gained by a particular development are usually considered with reference to—

1. Cost of manufacture.
2. Thermal efficiency.
3. Reliability.
4. Weight of the engine and the space occupied.

The only advantage in the use of high-pressure steam is an increase of thermal efficiency, for initial cost is increased and reliability diminished.

To illustrate the gain in efficiency, a high-powered steam turbine for a power station, working under two conditions, has been taken, the vacuum in each case being 29 inches of mercury.

	Steam Pressure. Lbs. per square inch absolute.	Superheat. Degrees F.	Total temperature. Degrees F.
a.	200	318	700
b.	1,000	153	700

The Rankine efficiency for (a) is 33·8 per cent., and for (b) 40·2 per cent. Taking into account the losses in the turbine

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and the power for auxiliaries, these figures become (a) 26 per cent. and (b) 28·5 per cent. The greater drop of efficiency at the higher pressure is chiefly due to the increased wetness of the steam in the final stage of expansion. In order to raise the latter figure, regenerative feed-heating should be adopted, tapping steam at, say, three points of the expansion to heat the feed water successively. With three-stage feed heating, efficiency (b) would be raised to 32 per cent. Thus there is quite a substantial increase at high pressure, but probably not sufficient to meet the increased capital cost. Mr. Guy, from whose paper* these figures are taken, considers that higher pressures than about 400 lbs. per square inch give no financial advantage. In this connection, the following particulars of two power stations are interesting:—

Dalmarnock, Glasgow. Steam pressure, 260 lbs. per square inch; total temperature, 710 degrees F.; one feed-heating stage; best overall efficiency, 20·8 per cent. This figure compares approximately with 26 per cent. for (a) above × 0·8 for boiler and generator efficiency.

Weymouth, Boston, U.S.A. Steam pressure, 1,200 lbs. per square inch; total temperature, 700 degrees F.; three feed-heating stages; best overall efficiency, 25 per cent. This figure compares approximately with 32 per cent. for (b) above × 0·8 for boiler and generator efficiency.

The principal troubles experienced at increased pressures are due to the increased temperature of the water, causing, firstly, more pronounced deposition on the boiler tubes of the salts dissolved in the water, owing to the decreased solubility of the salts; and, secondly, increased corrosive action. In the first case, the danger is caused by the heat drop through the scale deposited on the inside of the tube, combined with the higher water temperature. The outside of the tube is liable to reach a high temperature, and if of mild steel, the strength may be dangerously reduced. To combat this requires the elimination

* Proc. Inst. of Mechanical Engineers, 1927, vol. 1, p. 99.

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of the scale by evaporated make-up, and close attention to condenser leakage; possibly special heat-resisting steel tubes would also be necessary. To prevent corrosion, reduction of the oxygen content of the feed water to below $\frac{1}{10}$ c.c. per litre is essential.

In marine turbine installations, the tendency is to follow land practice in adopting higher pressures. For instance, the "Duchess of Atholl," the 20,000-ton liner launched last year, is designed for 370 lbs. per square inch pressure and 700 degrees F. total temperature. The boiler arrangement includes both Yarrow water-tube and Scotch boilers, and allows the former to be fed with pure condensate.

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THE "JAMES WATT" DINNER.

THE Annual "James Watt" Dinner was held in the Banqueting Hall of the Grosvenor Restaurant, Glasgow, on Friday, 18th November, 1927. Mr. R. D. Moore, B.Sc., President of the Institution, occupied the chair, and amongst those present were The Right Hon. The Lord Provost of Glasgow, David Mason, Esq., O.B.E.; The Most Hon. The Marquis of Douglas and Clydesdale; The Right Hon. The Earl of Stair, D.L., D.S.O.; The Right Hon. Lord Lamington, G.C.M.G., G.C.I.E.; Sir Steven Bilsland, Bt., M.C.; Sir Thomas Paxton, Bt., LL.D.; Air-Vice-Marshal Sir Sefton Brancker, K.C.B., A.F.C.; Sir John M. MacLeod, Bt., D.L., LL.D.; Sir Joseph W. Isherwood, Bt.; Sir Thomas Bell, K.B.E.; Major Walter Elliot, M.C., D.Sc., M.P.; Mr. William Henderson; Mr. A. J. Campbell, Past President; Sir Alexander M. Kennedy; Sir Henry S. Keith, Chairman, Education Authority of Lanarkshire; Sir Henry Mechan, LL.D.; Mr. Maurice S. Gibb, C.B.E., President, North East Coast Institution of Engineers and Shipbuilders; Mr. S. G. Visker, w.i.; Rev. Lauchlan MacLean Watt, D.D.; Sir John S. Samuel, K.B.E.; Major-General H. F. Thuillier, C.B., C.M.G.; Sir Charles J. Cleland, K.B.E., M.V.O., D.L.; Mr. Harold E. Yarrow, C.B.E., Past President; Mr. J. Howden Hume, Past President; Mr. F. J. Shepherd; Mr. A. J. T. Taylor; Mr. Robert Traill; Mr. James Morton, Chairman, Glasgow Chamber of Commerce; Eng.-Capt. P. J. Shrubsole, R.N., D.S.O.; Mr. John Craig, C.B.E., President, West of Scotland Iron and Steel Institute; Commander A. R. A. MacDonald, R.N.; Mr. Sam Mavor, Member of Council; Mr. George A. Mitchell; Mr. D. Macfarlane MacLeod, President, Institution of Electrical Engineers, Scottish Centre; Mr. A. Galbraith; Mr. Adam Hunter, Member of Council; Provost John Garrick, Dumbar-

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ton; Dr. James Montgomerie, Member of Council; Prof. J. J. Welch, D.Sc.; Mr. J. Foster King, C.B.E.; Mr. A. Scott Younger, B.Sc.; Mr. E. W. Fraser-Smith, M.A., Secretary, North East Coast Institution of Engineers and Shipbuilders; Mr. S. E. Flack, President, The Institute of Metals, Scottish Local Section; Mr. A. W. Stewart; and Mr. F. C. Stewart.

The Croupiers were Mr. James Brown, C.B.E.; Prof. J. D. Cormack, C.M.G., C.B.E., D.Sc.; Prof. Percy A. Hillhouse, D.Sc.; and Mr. W. W. Marriner.

The loyal toasts and "The Immortal Memory of James Watt"—the latter in silence—having been honoured on the call of the Chairman,

Major WALTER ELLIOT, Under-Secretary of State for Scotland, proposed "The Mercantile Marine." James Watt was, he said, associated with one of the greatest changes in industry, and in the carrying of passengers and goods by sea. But Watt, who changed industry and commerce in every way, was imbued with the spirit of the mercantile marine, and the men who ran the big cargo steamers of to-day were precisely of the same type as the men who navigated the sailing ships of Watt's time across the seas. The spirit of the mercantile marine of Great Britain was the pride and glory of the country. The spirit of the industrial age which was enshrined in the grand old sailing ships had come down to the present day. This was clearly seen in the pride that the men of to-day had in the great engines which they produced and operated. It was the spirit of the British mercantile marine that induced Joseph Conrad to become a British sailor, and Conrad believed that to work on the ships of Great Britain was the most honourable thing a man could do. He (Major Elliot) believed that ships even greater and better than those now in existence would be built, and that the spirit of British sailors was as great and as noble as ever it had been.

Mr. WILLIAM HENDERSON, in replying, said there was a time when the mercantile marine was flourishing. Some of them almost remembered that time. In those good days one sailor would say to another, as they parted at the quays, "I will see

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you in Liverpool." Now one said to the other, "I will see you in the Gareloch." The Chancellor of the Exchequer had been trying to show, by fact, figures, and percentages, that the trade of this country was improving. But the mercantile marine had developed a horror of percentages, which could be made to prove many remarkable things. The services rendered by the mercantile marine during the war were many and varied, and perhaps the chief among them was the way in which merchant shipping contributed to the navigating knowledge of the Navy. He knew of one merchant ship that came into Scapa Flow and reported that every war vessel she had passed within the previous two days had asked for her position. The mercantile marine was largely dependent for its development and prosperity, not only on the free and increasing exchange of commodities between nations, but also on the free and increasing intercourse of the peoples of the world. Since the German and United States Governments had reached an agreement about visas, the number of American visitors to Germany had doubled. Any help that Major Elliot could give to bring about a similar agreement between Great Britain and the United States would redound to the prestige of his Government, and would make for the elevating of international relations and the furtherance of the peace of the world. They were all indebted to Major Elliot for the many years of solid and persevering labour which he had given for the improvement of industry and for the welfare of the country.

Mr. A. J. CAMPBELL, Past President, in proposing "Our Guests," remarked that James Watt was one of the great benefactors of the race, especially to those who lived in Scotland, and he was sure the guests had all been prompted to come there by the thought of that memory and entirely actuated by the fact of honouring it. In coupling the name of Air-Vice-Marshal Sir Sefton Brancker with the toast, he said his presence in the city carrying on the work of promulgating the ideas of aviation was a happy circumstance. James Watt was the author of what made the past century to them a success, and he was quite sure that the present century would gain

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prosperity from the work of such pioneers as Sir Sefton Brancker and those associated with him in aviation. They were proud of what had been done by our country in this connection.

Sir SEFTON BRANCKER, replying, said he represented the youngest industry in the country—air transport, and he was very proud to hear from Mr. Henderson that the old mercantile marine used to give the Navy their real knowledge of navigation, because his little baby was doing just the same. It was beginning to teach the Royal Air Force how to navigate. He was always delighted to come to Glasgow, although he had the misfortune to live in the South, where people did not appreciate Glasgow. They thought it was a cold, dour place with an awful climate. He did not agree. Glasgow had courage tempered with caution—financial caution—but with a determination, once it put its hand to the plough, to pull anything through. Proceeding, Sir Sefton said he had the single-track mind, and that single track was aviation. Glasgow recently had in this connection shown some enterprise in the fact that there had been started in the city a light aeroplane club. This was really a sound proposition, and he asked old and young in the company before him to go in for flying. It was the best thing in the world for their health. Aviation was looked upon as a dangerous pursuit, but commercial aviation, he assured them, was extraordinarily safe, and very much safer than a French railway train. Everybody had heard of the horrors of crossing the English Channel. He advised travelling by air, as air sickness was much better than sea sickness. Referring to the organised air routes in the world to-day, Sir Sefton pointed out that this country had still a great deal to do in this connection. The position was that air transport to-day did not pay, but it would pay, and when that time came there would be an enormous demand for commercial aircraft—a colossal demand, far greater than any air force could possibly cope with. When that demand came it was absolutely necessary that we should capture trade just as trade was captured in the past by our mercantile marine.

In the past we had been a nation of seamen, and we had

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in the future to become a nation of airmen. Glasgow depended on the shipping industry for its prosperity, and its citizens should now be making ready for the great boom in commercial aircraft that was coming. This country had not a rival in the world in aviation, just as it had not a rival in the world in shipping, and Glasgow must be in this great movement which was just beginning.

On the call of Mr. Maurice S. Gibb, the health of the Chairman was pledged, and Mr. Moore briefly acknowledged.

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MINUTES OF PROCEEDINGS.

SEVENTY-FIRST SESSION.

The First General Meeting was held in the Rankine Hall, 39 Elmbank Crescent, Glasgow, on Tuesday, 4th October, 1927, at 7.30 p.m.

Mr. A. J. Campbell, the retiring President, occupied the chair.

The Minutes of the Annual General Meeting, held on 12th April, 1927, and of the Summer Meeting, held jointly with the North East Coast Institution of Engineers and Shipbuilders, at Glasgow, on Tuesday and Wednesday, 21st and 22nd June, 1927, having been printed and circulated amongst the members, were held as read, and signed by the Chairman.

Thereafter, Mr. Campbell thanked the members for the kindness and courtesy they had at all times extended to him during his term of office, and formally introduced the new President, Mr. R. D. Moore, B.Sc. Mr. Moore, he said, had always shown a great interest in the affairs of the Institution, and was ever ready to help in whatever way he could to carry on the work.

Mr. Moore then took the chair, and delivered his inaugural address.

On the motion of Mr. A. J. Campbell, seconded by Mr. Harold E. Yarrow, C.B.E., Past President, Mr. Moore was accorded a hearty vote of thanks for his address.

A paper entitled "The Industrial Engineer," by Mr. Alfred J. T. Taylor, was read.

The following candidates were elected:—

As Members.

Blythe, George Edward Kevin, B.Sc., Ph.D., Engineer, Ael-Y-Bryn, 20 Pantygwydr Road, Uplands, Swansea.

Critchley, Herbert Lawson, Engineer, Messrs. Babcock & Wilcox, Ltd., Renfrew.

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GRAY, WALTER GIBB, Steelmaker, The Steel Company of Scotland, Ltd., 37 Renfield Street, Glasgow, C.2.

MAXWELL, JOHN MCMILLAN, Engineer, 34 Robertson Street, Greenock.

MORRISON, WILLIAM JAMES, Engineer Manager, 8 Maxwell Drive, Pollokshields, Glasgow, S.1.

SMITH, ALBERT VICTOR, Engineer, 40 Cornwall Terrace, Bradford.

THOMSON, ALEXANDER, Engineer, 8 Colliertree Road, Airdrie.

From an Associate Member.

HAMILTON, ALEXANDER, Engineer, Asiatic Petroleum Company (North China), Ltd., 1 The Bund, Shanghai, China.

AS ASSOCIATE MEMBERS.

OSMAN, AHMED, Engineer, 4 King's Avenue, Old Trafford, Manchester.

TELLIS, CHARLES SEBASTIAN JOAQUIM, B.A., B.Sc., Engineer, The University, Glasgow.

AS AN ASSOCIATE.

SHIOZAWA, Captain KOICHI, I.J.N., D.S.O., Naval Attache to the Japanese Embassy, Broadway Court, Broadway, Westminster, London, S.W.

AS A STUDENT.

BOTTOMLEY, GEORGE STANLEY, Apprentice Engineer, 44 Ashwell Road, Heaton, Bradford, Yorks.

The Second General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 18th October, 1927, at 7.30 p.m.

Mr. R. B. Mitchell, Vice-President, occupied the chair.

The discussion on the paper by Mr. Alfred J. T. Taylor, entitled "The Industrial Engineer," was begun and concluded.

On the motion of the Chairman, Mr. Taylor was accorded a vote of thanks for his paper.

A paper entitled "British Engineering Export Problems," by Mr. William S. Murphy, was read.

The Third General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 8th November, 1927, at 7.30 p.m.

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Mr. R. D. Moore, B.Sc., President, occupied the chair.

The Minutes of the First and Second General Meetings, held on 4th and 18th October, 1927, respectively, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

The discussion on the paper by Mr. William S. Murphy, entitled "British Engineering Export Problems," was begun and adjourned.

A paper entitled "City Local Passenger Transport," by Mr. W. C. Easton, B.Sc., was read, and the discussion thereon begun and adjourned.

The following candidates were elected:—

AS MEMBERS.

COUSINS, ALEXANDER MCPHEDRAN BROWN, Consulting Engineer and Marine Surveyor, 75 Buchanan Street, Glasgow, C.1.

COUSINS, GEORGE MARSHALL, Consulting Engineer and Marine Surveyor, 75 Buchanan Street, Glasgow, C.1.

DRYSDALE, JOHN, B.Sc., Engineer, 6 Kelburn Avenue, Dumbreck, Glasgow, S.1.

GILLESPIE, JAMES, Engineer, 105 Randolph Road, Jordanhill, Glasgow, W.2.

HAY, JOHN, Engineer, 36 Pleasance Street, Newlands, Glasgow.

SHORT, WILLIAM LLEWELLYN EVERETT, Engineer, The Cottage, Glasgow Road, Dumbarton.

WOOD, ROBERT CRAWFORD, Managing Director, Clyde Shipbuilding and Engineering Co., Ltd., 91 Newark Street, Greenock.

From Associate Member.

CRIGHTON, JOHN, Jun., Engineer, Hume Lodge, Tavistock Road, South Woodford, Essex.

AS ASSOCIATE MEMBERS.

DHAR, PULIN BEHARI, Engineer, 21 Bell Street, Renfrew.

EL-KHADEM, ARNIN, Engineer, Tanzim Department, Road Section, Public Works Department, Cairo, Egypt.

GANESH, SHIRA, Engineer, Pajoona, District and Pergana Jalaum (U.P.), India.

MALAK, BASHIR AHMAD, B.Sc., Engineer, Sanda Klan, Lahore, India.

SAH, PEN-HSIM, Engineer, 6 Daleview Avenue, Kelvindale, Glasgow, W.2.

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From Students.

LOGIE, JOHN SHARP, B.Sc., Engineer, 11 Aberconway Street, Whitecrook, Clydebank.

MCCRAE, NORMAN ALEXANDER, Consulting Engineer, Sutherland House, Surbiton, Surrey.

AS ASSOCIATES.

CARSON, JAMES ROGER, Manager, Glasgow Boiler and Ship Scaling Co., Ltd., 5 Ardgowan Terrace, Glasgow, C.3.

GORDON, ALEXANDER, Director, Messrs. J. & D. Hamilton, Ltd., 115 Port Dundas Road, Glasgow, C.4.

AS STUDENTS.

ANDERSON, ROBERT SLOAN, Engineer, 24 Church Street, Johnstone.

BALMER, WILLIAM, Engineer, Woodilee Cottages, Woodilee, Lenzie.

LAMBIE, THOMAS ROBERTSON, Engineer, Thornwood, Overton Crescent, Johnstone.

MURRAY, JAMES C., Apprentice Engineer, Greenside, 66 Princes Street, Glasgow, S.W.1.

The Fourth General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 22nd November, 1927, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

The discussion on the paper by Mr. William S. Murphy, entitled "British Engineering Export Problems," was resumed and concluded.

On the motion of the Chairman, Mr. Murphy was accorded a vote of thanks for his paper.

The discussion on the paper by Mr. W. C. Easton, B.Sc., entitled "City Local Passenger Transport," was resumed and concluded.

On the motion of the Chairman, Mr. Easton was accorded a vote of thanks for his paper.

A paper entitled "The Uses of Nickel Deposits for Engineering Purposes," by Mr. C. H. Faris, was read, and the discussion thereon begun and adjourned.

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The Fifth General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 6th December, 1927, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

The Minutes of the Third and Fourth General Meetings, held on 8th and 22nd November, 1927, respectively, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

A paper entitled "Recent Developments of the Exhaust-Steam Turbine," by Dr. Gustav Bauer, of Hamburg, was read, and the discussion thereon begun and adjourned.

The following candidates were elected:—

As Members.

KERR, JAMES MORTON, Civil Engineer, 54 Corrour Road, Newlands, Glasgow.

MAIN, HENRY, Shipbuilder, Errolbank, 9 Dalgleish Road, Dundee.

ROGERS, JOHN, B.Sc., Engineer, 4 Dargarvel Avenue, Dumbreck, Glasgow, S.1.

As Associate Members.

KHAN, FAZAL HAQ, B.Sc., Engineer, The University, Glasgow.

MILLIE, THOMAS HUTTON WILSON, Engineer, 6 Randolph Road, Broomhill, Glasgow, W.1.

STEVENSON, JOHN S. H., Engineer, Broombank, Moffat.

As Associates.

BROWN, JAMES RUTHVEN, Director, Messrs. Brown, Son & Ferguson, Ltd., Ravenslea, 59 Aytoun Road, Pollokshields, Glasgow, S.1.

BRUCE, NAISMITH DOUGLAS, Shipping Accountant, 12 Lorne Street, Glasgow, S.W.1.

STEWART, FRED. C., Director, Thermotank, Ltd., 150 Helen Street, Govan, Glasgow, S.W.1.

As Students.

BLANNER, ALLAN, Engineer, Danely, Uddingston.

CRAWFORD, BRYCE, Ship Draughtsman, Monaville, Dumbarton.

LATTA, JAMES, Apprentice Engineer, 23 Agnes Street, North Kelvinside, Glasgow.

MEIKLE, WILLIAM, Engineer, 41 Exeter Drive, Partick, Glasgow, W.1.

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The Sixth General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 20th December, 1927, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

On the recommendation of the Council, it was agreed to award premiums of books to the following authors of papers read before the Institution during session 1926-27:—

Author.	Title.	Value.
Dr. A. M. Robb,	"A Stability Chart for the Use of Shipmasters and Officers,"	£5.
Mr. Joseph G. Worker, B.S.,	"The Use, Improvements, and Test Results of the Multiple Retort Underfeed Stoker in the United States,"	£5.

The discussion on the paper by Mr. C. H. Faris, entitled "The Uses of Nickel Deposits for Engineering Purposes," was resumed and concluded.

On the motion of the Chairman, Mr. Faris was accorded a vote of thanks for his paper.

The discussion on the paper by Dr. Gustav Bauer, entitled "Recent Developments of the Exhaust-Steam Turbine," was resumed and concluded.

On the motion of the Chairman, Dr. Bauer was accorded a vote of thanks for his paper.

A paper entitled "Factors of Safety and Quality of Material," by Mr. W. H. Riddlesworth, M.Sc., M.Eng., was read, and the discussion thereon begun and adjourned.

The Seventh General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 10th January, 1928, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

The Minutes of the Fifth and Sixth General Meetings, held on 6th and 20th December, 1927, respectively, having been

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printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

Mr. W. H. Riddlesworth, M.Sc., M.Eng., in moving the adoption of the Report of the Council and Treasurer's Statement for session 1926-27, dealt in detail with the various items of the Report and Balance Sheet, and made particular reference to the work of the Students' Section, which, he thought, should receive every encouragement from members of the Institution.

Mr. J. L. Adam seconded the motion, which was then put to the meeting and carried unanimously.

The discussion on the paper by Mr. W. H. Riddlesworth, M.Sc., M.Eng., entitled "Factors of Safety and Quality of Material," was resumed and concluded.

On the motion of the Chairman, Mr. Riddlesworth was accorded a vote of thanks for his paper.

A paper entitled "The Pressure Detector," by Mr. Norman Young, was read, and the discussion thereon begun and adjourned.

The Eighth General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 24th January, 1928, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

The discussion on the paper by Mr. Norman Young, entitled "The Pressure Detector," was resumed and concluded.

On the motion of the Chairman, Mr. Young was accorded a vote of thanks for his paper.

A paper entitled "Some Notes on Deck Supports," by Mr. W. Henderson Carslaw, B.Sc., was read, and the discussion thereon begun and adjourned.

The Ninth General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 7th February, 1928, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

The Minutes of the Seventh and Eighth General Meetings,

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held on 10th and 24th January, 1928, respectively, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

The discussion on the paper by Mr. W. Henderson Carslaw, B.Sc., entitled "Some Notes on Deck Supports," was resumed and concluded.

On the motion of the Chairman, Mr. Carslaw was accorded a vote of thanks for his paper.

A paper entitled "The Buell System of Pulverised Coal Firing," by Dr. G. E. K. Blythe, B.Sc., was read.

The following candidates were elected:—

AS MEMBERS.

LANG, GAVIN MONTGOMERY, Engineer, 2 Sutherland Avenue, Maxwell Park, Glasgow, S.1.

MUNDIE, ROBERT, Engineer, 71 Marlborough Avenue, Broomhill, Glasgow, W.1.

AS ASSOCIATE MEMBERS.

LABIB, MOHAMMED TEWFIK, Engineer, 18 Broadfield Road, Hither Green, London, S.E.6.

MCCAW, JOHN CAMERON, Engineer, Malayan Tin Dredging Ltd., Batu Gajah, Perak, F.M.S.

MCGLASHAN, WILLIAM, Engineer, 2 Greenvale Terrace, Bonhill Road, Dumbarton.

RAHMAN, AHMAD SALAH ABDEL, Engineer, 18 Broadfield Road, Hither Green, London, S.E.6.

SENEVIRATNE, GANNAGODA DON IRVIN, Engineer, Ceylon Government Factory, Public Works Department, Colombo, Ceylon.

SMITH, JOHN, Engineer, 104 Leathwaite Road, Clapham Common, London, S.W.11.

STENHOUSE, JOHN, Engineer, 3 Howat Street, Glasgow, S.W.1.

VERGHESE, THOMAS, B.Sc., Civil Engineer, c/o Messrs. Peirce Leslie & Co., 14 Billiter Street, London, E.C.3.

From Students.

BURT, DAVID OGILVIE, B.Sc., Engineer, 57 Thorpe Road, Norwich.

MITCHELL, HUGH BELL, Engineer, 294 West Scotland Street, Glasgow, S.1.

AS A STUDENT.

BROOME, JOHN, B.Sc., Engineer, c/o Donaldson, 40 West End Park Street, Glasgow, C.3.

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The Tenth General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 21st February, 1928, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

The discussion on the paper by Dr. G. E. K. Blythe, B.Sc., entitled "The Buell System of Pulverised Coal Firing," was begun and concluded.

On the motion of the Chairman, Dr. Blythe was accorded a vote of thanks for his paper.

A paper entitled "An Investigation into Some Effects of Cold Drawing on the Strength and Endurance of Mild Steel," by Dr. R. M. Brown, was read.

The Eleventh General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 6th March, 1928, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

The Minutes of the Ninth and Tenth General Meetings, held on 7th and 21st February, 1928, respectively, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

A paper entitled "Television," by Mr. John L. Baird, was read.

On the motion of the Chairman, Mr. Baird was accorded a hearty vote of thanks for his paper.

An Extraordinary General Meeting was held at 39 Elmbank Crescent, Glasgow, on Monday, 12th March, 1928, at 8 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

A lecture on "Some Technical Problems of Broadcasting" was delivered by Capt. P. P. Eckersley, of the British Broadcasting Corporation.

On the motion of Mr. Harold E. Yarrow, C.B.E., Past President, Capt. Eckersley was accorded a hearty vote of thanks for his address.

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The Twelfth General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 20th March, 1928, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

On the recommendation of the Council, the following nominations for Office-Bearers were made:—

For Session 1928-29.

President - - - Mr. Ralph D. Moore, B.Sc.

For Sessions 1928-31

Vice-Presidents - Mr. John Anderson.
Prof. J. D. Cormack, C.M.G., C.B.E., D.Sc.
Mr. Archibald Gilchrist, O.B.E.
Mr. W. H. Riddlesworth, M.Sc., M.Eng.

Members of Council Mr. A. P. Cole, R.C.N.C.
Mr. N. O. Fulton.
Mr. S. J. Pigott.
Mr. S. B. Ralston.
Mr. J. A. Warren.
Mr. A. Scott Younger, B.Sc.

(Associate) Mr. Fred. C. Stewart.

The discussion on the paper by Dr. R. M. Brown, entitled "An Investigation into Some Effects of Cold Drawing on the Strength and Endurance of Mild Steel," was begun and adjourned.

A paper entitled "The Development of the Fiat Marine Oil Engine," by Mr. D. M. Shannon, was read, and the discussion thereon begun and adjourned.

The Annual General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 3rd April, 1928, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

The Minutes of the Eleventh General Meeting, held on 6th March, 1928, of an Extraordinary General Meeting, held on

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12th March, 1928, and of the Twelfth General Meeting, held on 20th March, 1928, having been printed and circulated with the notice calling the meeting, were held as read, and signed by the Chairman.

The following members were elected as Office-Bearers:—

For Session 1928-29.

President - - - Mr. Ralph D. Moore, B.Sc.

For Sessions 1928-31.

Vice-Presidents - Mr. John Anderson.
Prof. J. D. Cormack, C.M.G., C.B.E., D.Sc.
Mr. Archibald Gilchrist, O.B.E.
Mr. W. H. Riddlesworth, M.Sc., M.Eng.

Members of Council Mr. A. P. Cole, R.C.N.C.
Mr. N. O. Fulton.
Mr. S. J. Pigott.
Mr. S. B. Ralston.
Mr. J. A. Warren.
Mr. A. Scott Younger, B.Sc.

(Associate) Mr. Fred. C. Stewart.

The discussion on the paper by Dr. R. M. Brown, entitled "An Investigation into Some Effects of Cold Drawing on the Strength and Endurance of Mild Steel," was resumed and concluded.

On the motion of the Chairman, Dr. Brown was accorded a vote of thanks for his paper.

The discussion on the paper by Mr. D. M. Shannon, entitled "The Development of the Fiat Marine Oil Egine," was concluded.

On the motion of the Chairman, Mr. Shannon was accorded a vote of thanks for his paper.

A paper entitled "The Balance of Internal-Combustion Engines," by Prof. William Kerr, Ph.D., A.R.T.C., was read.

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The following candidates were elected:—

As Members.

Clapham, William Henry, Shipbuilder, 87 Union Street, Glasgow, C.1.

Lowrison, William Rutherford, Shipbuilder, 113 St. Vincent Street, Glasgow, C.2.

From an Associate Member.

Drysdale, John Whitehead Wilson, B.Sc., Engineer, 16 Whittingehame Drive, Glasgow, W.2.

As Associate Members.

Heckie, Bert Hamilton, Machinery Merchant, 88 Queensborough Gardens, Hyndland, Glasgow, W.2.

Paul, Jaggit Singh, Engineer, Shahabad Cement Co., Ltd., G. I. P. Railway, Deccan, India.

From Students.

Finlator, Thomas Fairburn, Engineer, 28 Arkleston Road, Paisley.

Lawson, David Frier, Ship Draughtsman, 14 Queen's Gate, Dowanhill, Glasgow, W.2.

As Students.

Fullarton, Joseph, Apprentice Engineer, 1529 Dumbarton Road, Scotstoun.

Rodger, Alexander, Engineer, 11 Haldane Street, Scotstoun.

Smith, Charles Hector, Apprentice Engineer, Viewpark, Stepps, Glasgow.

The Thirteenth General Meeting was held at 39 Elmbank Crescent, Glasgow, on Tuesday, 17th April, 1928, at 7.30 p.m.

Mr. R. D. Moore, B.Sc., President, occupied the chair.

The discussion on the paper by Prof. William Kerr, Ph.D., A.R.T.C., entitled "The Balance of Internal-Combustion Engines," was begun and concluded.

On the motion of the Chairman, Prof. Kerr was accorded a vote of thanks for his paper.

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REPORT OF THE COUNCIL.

SESSION 1926-27.

The Council have pleasure in presenting their Report on the proceedings of the Institution during Session 1926-27.

THE ROLL.

The changes in membership during the year ending 30th September, 1927, are shown in the following statement:—

	Session 1925-26.	Session 1926-27.
Honorary Members - - -	10	10
Members - - - - -	1,019	1,002
Associate Members . - -	301	319
Associates - - - -	63	67
Students - - - - -	209	198
	1,602	1,596

The number of admissions to the register during the year was 89, while the transfers from a lower to a higher grade of membership were 17. Allowing for deletions on account of deaths, resignations, and non-payment of subscriptions, there is a decrease in membership of 6.

MEMBERS DECEASED.

The Council deeply regret to report the loss by death of the following members:—

Members.—Peter MacLeod Baxter, Glasgow; William Reid Bell, Melbourne, Australia; Thomas Browne Bingham, Wemyss Bay; William Bow, Paisley; John Whyte Boyd, Glasgow; Sir James Kemnal, London; John Henry Macalpine, New York; John Macdonald, Glasgow; John McNeil, Prestwick; James Steele, Lanark; Sinclair Sutherland, Uplawmoor, Renfrewshire; John Croysdale Tannett, Paisley; Benson Taylor, London; Duncan McNaughton Wallace, Glasgow; Robert Williamson, Newport (Mon.); Daniel Wilson, Gourock.

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Associate Members.—Andrew Stirling, Dumbarton; Thomas Hunter Baird, Skelmorlie.

Memoirs of these are published in Vol. LXX, page 963, *et seq.*, of the Institution's proceedings.

Meetings and Papers.

Thirteen general meetings were held during the session, and at the opening meeting on 5th October the President delivered an address. After commenting on the industrial situation, he referred to the coal and oil supplies of the world, and to the increased production of internal-combustion engines for marine purposes.

Following is a list of the papers presented and discussed:—

"Large-Grained Steel Wire and a Comparison with Rope Wire," by Dr E. M. Horsburgh, M.A.

"Steam *versus* Diesel Machinery for Cargo Vessels," by W. G. Cleghorn, B.Sc.

"A Stability Chart for the Use of Shipmasters and Officers," by Dr. A. M. Robb.

"Marine Oil Engines," by D. M. Shannon.

"The Clock and Striking Mechanisms for the Great Bell of the University of Bristol," by Prof. David Robertson, D.Sc.

"High Elastic Limit Steel for Shipbuilding and Marine Engine Purposes," by T. M. Service.

"The Application of the Double-Acting Diesel Engine to Ship Propulsion," by Robert Love.

"The Development of Industrial Welfare Work," by the Rev. Robert R. Hyde.

"Manœuvring of Ships. Part III. Unbalanced Rudders Behind Single-Screw Ships. Effect of Varying Fulness of Form," by G. H. Bottomley.

"The Application of Precooling by Primary Evaporation and Multiple Effect Compression to CO_2 Refrigerating Machines," by Henry Brier.

"The Machinery Installation of the Ex-German Battleship 'Grosser Kurfürst,'" by John S. Brown, M.B.E., A.R.T.C.

"Electrical Power in Ports and Harbours," by W. A. Perry.

"Modern Developments in Pulverised Coal Firing," by R. Jackson.

"The Use, Improvements, and Test Results of the Multiple Retort Underfeed Stoker in the United States," by Joseph G. Worker, B.S.

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Joint Summer Meeting.

A Joint Meeting of the Institution and the North East Coast Institution of Engineers and Shipbuilders was held at Glasgow from 20th to 23rd June, 1927, inclusive.

On Monday evening, 20th June, the Institution was at home to the visitors in the Institution's rooms, and on Tuesday morning the Conference was opened, in the Rankine Hall, by the Right Hon. Lord Weir of Eastwood, P.C., D.L., LL.D.

During the Conference the following papers were read:—

"Historical References to the Progress in the Use of High-Pressure Steam," by James Mollison.

"The Trade Value of Simplification and Standardisation in the Details of Ships and their Machinery," by C. le Maistre, C.B.E.

"Economy in Shipbuilding; Some Lines of Progress," by John McGovern.

"Motor Yachts and Motor Yachting on the Clyde," by F. L. MacLaren.

Visits were made to several engineering and shipbuilding works in Glasgow and neighbourhood, and the social functions included a Conversazione in the City Chambers by the invitation of the Right. Hon. The Lord Provost (David Mason, Esq., O.B.E.) and the Corporation of Glasgow; a dinner and dance in the Central Hotel; and an excursion by the high-pressure turbine steamer "King George V" to Brodick, Arran.

The aforementioned papers, with the discussions thereon, and a full report of the Conference, will be found in Vol. LXX of the Institution's proceedings.

Awards for Papers Read.

Premiums of books were awarded to the following authors of papers read before the institution during session 1925-26:—

Author.	Title.	Value.
Prof. William Kerr, Ph.D., A.R.T.C.	"Failure of Metals by Creep,"	£5.
Mr. John Anderson,	"Possible Future Developments in Atlantic Express Passenger Services,"	£4.
Mr. G. J. Lugt,	"The Werkspoor Diesel Engine,"	£4.

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Appointment of Representatives.

The Council made the following appointments of members to represent the Institution on the subjoined Committees:—

Board of Trade Consultative Committee—Mr. S. J. Pigott, *vice* Mr. C. Randolph Smith, resigned.

British Engineering Standards Association: Bright Bolts and Nuts—Eng.-Capt W. Onyon, R.N. (ret.), M.V.O.

British Engineering Standards Association: Sectional Committee on Machine Parts; their Gauging and Nomenclature—Mr. J. Howden Hume, *vice* Dr. T. Blackwood Murray, retired.

British Engineering Standards Association: Sectional Committee on Petroleum Products—Mr. A. J. T. Taylor, *vice* Dr. T. Blackwood Murray, retired.

Honours Conferred upon Members.

His Majesty the King conferred the Order of Merit on Sir Charles A. Parsons, K.C.B., M.A., D.Sc., LL.D., D.Eng., and a Knighthood on Mr. Henry Mechan; and the Senate of the Glasgow University bestowed the honorary degree of Doctor of Laws on Prof. Herbert C. Sadler, D.Sc.

Presentations to the Institution.

A sum of £50 from Mr. N. O. Fulton, the yearly interest on which is to be devoted to the prize fund for papers read before the Students' Section.

A framed portrait in oils of George Stephenson, the eminent engineer; presented by Mr. Hugh A. Brown.

Annual Dinner.

The "James Watt" Dinner was held in the Banqueting Hall of the Grosvenor Restaurant, Glasgow, on Friday evening, 19th November, 1926, and was attended by 355 members and guests. Mr. A. J. Campbell, President, occupied the chair.

Students' Section.

At the first general meeting on 15th October, 1926, Mr. W. H. Riddlesworth, M.Sc., M.Eng., delivered his Presidential Address on "Compressed Air."

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Six other meetings were held, at which the following papers were read and discussed:—

"Machinery Installation of a Cargo Steamer," by J. G. McLean.
"Design of the High-Speed Steam Engine," by W. C. MacMillan.
"Recent Developments in Marine Auxiliaries," by John R. Lang.
"Development of Regulations Affecting Ship Design," by R. B. Shepheard, B.Sc.
"Use of Non-Ferrous Materials in Shipbuilding and Engineering," by J. Donaldson.
"The Centrifugal Clarification of Oil," by J. A. B. Rennie, B.Sc.

Premiums of books, value £2 each, were awarded to Mr. John R. Lang and Mr. J. A. B. Rennie, B.Sc., respectively, for their papers.

A series of visits to the following works was organised by the Students' Council, and the Students desire to record their thanks to the managements and staffs of these establishments for the facilities afforded and the courtesy shown during the visits:—

Ipco Rubber and Waterproofing Co., Ltd., Netherton Works, Anniesland.
Messrs. James Hendry, Ltd., Bridgeton Laminated Leather Works.
Messrs. Robert Craig & Sons, Ltd., Moffat Paper Mills, Airdrie.
Orchard Sugar Co., Ltd., Ingleston Street Refinery, Greenock.
North British Locomotive Co., Ltd., Hyde Park Works, Springburn.
Messrs. Harland & Wolff, Ltd., Govan.
Albion Motor Car Co., Ltd., Scotstoun.
United Alkali Co., Ltd., St. Rollox.

On Friday evening, 3rd December, 1926, a Dance was held in the Institution's rooms. The popularity of this annual function is evident from the fact that the demand for tickets exceeded the available accommodation.

A Smoking Concert was held in the Smoking Room of the Institution on Friday evening, 25th February, 1927, Mr. W. H. Riddlesworth, M.Sc., M.Eng., presiding.

The Sports Committee of the Students' Council organised a Billiards Tournament during the session for the Moore Cup, the trophy being won by Mr. Robert Brown.

Mr. D. Cameron was the winner of the Silver Challenge Cup in a golf competition played over Littlehill Course during the summer.

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Capt. S. R. Aitken, F.R.G.S., was elected President, and Mr. Angus Campbell, President-Elect, for session 1927-28.

Tenant Societies.

The following societies hold their sessional meetings in the Institution's premises:—

British Empire Shakespeare Society.
British Music Society.
Glasgow and West of Scotland Association of Foremen Engineers and Draughtsmen.
Glasgow Institute of Architects.
Glasgow Master Wrights' and Builders' Association.
Glasgow Practical Psychology Club.
Institute of Metals—Local Section.
Institution of Civil Engineers—Glasgow Association of Students.
Scottish Society of Industrial Welfare Supervisors.
Society of Chemical Industry—Glasgow Section.
Society of Consulting Marine Engineers and Ship Surveyors—Scottish District.

Finance.

The surplus revenue for the year ending 30th September, 1927, as shown in the Treasurer's Statement, appended hereto, is £40 4s.

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TREASURER'S
INCOME AND EXPENDITURE ACCOUNT FOR GENERAL

ORDINARY INCOME.				1926-1927.			*1925-1926.*		
I.	*Annual Subscriptions received*—								
	Members	£2,629	0 0						
	Associate Members ...	573	5 0						
	Associates	130	10 0						
	Students	135	15 0						
				£3,468	10	0	*£3,528*	*15*	*0*
II.	*Arrears of Subscriptions recovered*			97	10	0	*66*	*0*	*0*
III.	*Sales of "Transactions"*			147	9	6	*206*	*7*	*5*
IV.	*Interests and Rents*—								
	Interest on Deposit Receipts	44	6 4						
	Interest on Clyde Trust Mortgages	212	7 1						
	Interest on 5% War Stock	112	10 0						
	Sundry Rents	631	5 9						
				1,000	9	2	*1,022*	*10*	*10*
V.	*Advertisement Receipts, less cost of Printing*			298	10	10	*280*	*7*	*2*
				£5,012	9	6	*£5,104*	*0*	*5*

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STATEMENT.

THE YEAR ENDING 30TH SEPTEMBER, 1927.

FUND.

ORDINARY EXPENDITURE.			1926-1927.	*1925-1926.*
I. *Management Expenses*—				
Salaries	£1,416 13 2			
Stationery, Postages, etc.	80 13 5			
General Printing	180 3 6			
Office Expenses	56 0 0			
Coffee Room Account	20 3 1			
Lithography	153 5 9			
Travelling Expenses	19 16 10			
Library Books, *less* Int. on Mr. Fullerton's Donation, £2 5	16 3 6			
		£1,942 19 3		
II. *House Expenses*—				
Feu Duty, Taxes, and Insurance	£635 3 4			
Caretaker and Cleaning	321 2 10			
Maintenance and Repairs	251 14 11			
Heating and Lighting	207 19 5			
Depreciation—Furniture and Fittings	50 0 0			
		1,466 0 6		
			£3,408 19 9	*£2,985 6 2*
III. "*Transactions*" *Expenses*—				
Printing and Binding	£1,256 4 0			
Less Int. on Sir Hugh Reid's Donation	90 0 0			
		1,166 4 0		
Postages		129 6 1		
Reporting		53 5 6		
Delivery of Volume (Est.)		68 0 0		
			1,416 15 7	*1,349 15 7*
EXTRAORDINARY EXPENDITURE				*654 1 5*
Asphalting Roof			146 10 2	
Surplus carried to Balance Sheet			40 4 0	*114 17 3*
			£5,012 9 6	*£5,104 0 5*

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BALANCE SHEET, AS AT

LIABILITIES.				As at 30th Sept., 1927.			*As at 30th Sept., 1926.*		
I. *General Capital Account*—									
As at 1st October, 1926			£32,627 17 8						
Entry Money			58 0 0						
Surplus from Revenue ...			40 4 0						
				£32,726 1 8			*£32,627 17 8*		
II. *Life Members' Subscriptions*			... ...	1,722 2 0			*1,677 2 0*		
III. *Feu-Duty and Taxes accrued*			... ...	165 0 0			*190 0 0*		
IV. *Sundry Creditors*			... ...	1,425 5 5			*1,284 4 6*		
V. *Subscriptions paid in advance*			... ...	99 10 0			*99 10 0*		
VI. *Social Fund*			... ...	155 7 0			*153 3 2*		
VII. *Medal Funds*—									
Marine Engineering—									
Balance as at 1st Oct., 1926	£1,160 6 1								
Int. received ...	43 9 3								
	£1,203 15 4								
Less Awards ...	13 0 0								
			£1,190 15 4						
Railway Engineering—									
Balance as at 1st Oct., 1926	781 17 10								
Int. received ...	29 6 0								
			811 3 10						
Students'—									
Balance as at 1st Oct., 1926	£615 14 11								
Less to Special Donations ...	50 0 0								
	£565 14 11								
Int. received ...	23 1 8								
Grant from "Buchanan and Ewing Bequests"	50 0 0								
	£638 16 7								
Less Awards and cost of Technical Books ...	50 0 0								
			£588 16 7						
				2,590 15 9			*2,557 18 10*		
VIII. *Trust Funds* —									
See Separate Statement ...			... ...	2,152 6 0			*2,050 0 0*		
				£41,036 7 10			*£40,639 16 2*		

ON BEHALF OF THE COUNCIL,

RALPH D. MOORE, *President.*

ROBT. THOS. MOORE, *Honorary Treasurer.*

GLASGOW, *15th December*, 1927.—I have audited the Books and Accounts of 30th September, 1927, and have to report that I have obtained all the information Sheet is properly drawn up so as to exhibit a true and correct view of the state my information and the explanations given to me, and as shown by the Books.

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30TH SEPTEMBER, 1927.

ASSETS.			As at 30th Sept., 1927.	As at 30th Sept., 1926.
I. *Buildings Account*			£25,000 0 0	*£25,000 0 0*
II. *Furniture and Fittings* ...	£400 0 0			
Less Depreciation	50 0 0			
			350 0 0	*400 0 0*
III. *Books in Library*—				
Valued at, say			500 0 0	*500 0 0*
IV. *Investment Account*—				
Clyde Trust Mortgages ...	£4,500 0 0			
5% War Stock (1929-1947)	2,191 6 6			
			6,691 6 6	*6,691 6 6*
V. *Medal Funds Investments*—				
Clyde Trust Mortgages ...	£1,900 0 0			
On Deposit Receipt... ...	689 1 7			
			2,589 1 7	*2,556 5 4*
NOTE.—Balance of £1 14 2 since lodged on Deposit Receipt.				
VI. *Trust Funds*—				
See Separate Statement			2,150 0 0	*2,050 0 0*
VII. *Arrears of Subscriptions*—				
Session 1926-27—				
Members	£108 0 0			
Associate Members ...	57 5 0			
Associates	5 10 0			
Students	18 0 0			
	£188 15 0			
Previous Sessions—				
Members ... £39 0 0				
Assoc. Members 10 10 0				
Students ... 5 5 0				
	£54 15 0			
Total	£243 10 0			
Valued at, say			50 0 0	*50 0 0*
VIII. *Rents, Interests, etc., accrued*			681 2 10	*443 2 8*
IX. *Cash*—				
In Bank on D/R	£1,951 12 9			
On Current Account ...	113 3 11			
Cash on Hand	60 0 3			
			2,124 16 11	*2,049 1 8*
			£41,036 7 10	*£40,639 16 2*

the Institution of Engineers and Shipbuilders in Scotland for the year ending and explanations I have required, and that, in my opinion, the foregoing Balance of the Institution's affairs as at 30th September, 1927, according to the best of

DAVID BLACK, C.A., *Auditor.*

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TRUST FUNDS.

Sir Hugh Reid Fund													
Donation			£2,000	0	0								
Interest			90	0	0								
			£2,090	0	0								
Less transferred to Printing and Binding Account ...			90	0	0								
						£2,000	0	0					
James Fullerton Fund.													
Donation			£50	0	0								
Interest			2	5	0								
			£52	5	0								
Less transferred to Library Books Account			2	5	0								
						50	0	0					
N. O. Fulton Fund.													
Donation			£50	0	0								
Interest			1	4	10								
						51	4	10					
W. J. Miller Fund.													
Bequest			£50	0	0								
Interest			1	1	2								
						51	1	2					
						£2,152	6	0					

Clyde Trust Mortgage (4½%) ...	£2,000	0	0					
						£2,000	0	0
Clyde Trust Mortgage (4½%) ...	£50	0	0					
						50	0	0
Clyde Trust Mortgage (5%) ...	£50	0	0					
						50	0	0
Clyde Trust Mortgage (5%) ...	£50	0	0					
						50	0	0
						£2,150	0	0
Balance in Bank and on Hand						2	6	0
						£2,152	6	0

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REPORT OF THE LIBRARY COMMITTEE.

During the session the accessions to the Library were 747 volumes and pamphlets. Of these 26 were Board of Trade Reports on Boiler and Steam-pipe Explosions; 45 British Engineering Standards Association publications; 77 volumes of Abridgments of Specifications of Patents; 35 volumes and pamphlets by donation; 505 volumes and pamphlets by exchange, and 59 volumes by purchase.

In addition to the books consulted in the Library and Reading-Room, 796 were loaned to 547 borrowers. This number includes 533 complete works, 88 volumes of transactions, proceedings of technical institutions, etc., 144 periodicals, etc., and 31 Abridgments of Specifications.

The Institution exchanges transactions with 61 scientific societies; there are also received in exchange 74 periodicals, 28 being weekly, 1 fortnightly, 43 monthly, 1 bi-monthly, and 1 quarterly.

The Institution possesses a set of Abridgments of Specifications of Patents from the year 1617, and files of the principal periodicals are kept.

The Library Committee will be pleased to receive gifts of technical books, etc., to be preserved in the Library for reference.

LIBRARY ACCESSIONS.

By Donation.

Abridgments of Specifications of Patents. 77 volumes. Series 1916-1920. From the Patent Office.

Bedson, J. P., and Primrose, J. S. G. Rod Rolling and Wire Drawing. Glasgow. 1927. pph. From Mr. Primrose.

Agent General for Western Australia.
Bretnall, R. W., Chapman, F., and Glauret, L. Bulletin No. 88. 1926. pph. Feltmann, F. R. Bulletin No. 91. 1925. pph. Talbot, H. W. B. Bulletin No. 87. 1926. pph. Talbot, H. W. B., and Simpson, E. S. Bulletin No. 85. 1926. pph. Bulletin No. 93. 1927. pph. Perth, Western Australia. From the Agent General.

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British Engineering Standards Association Publications:—

British Standard Tables of Pipe Flanges. (For Land Use). No. 10. 1926.

British Standard Specification for Indicating Ammeters, Voltmeters, Wattmeters, Frequency and Power-Factor Meters. No. 89. 1926.

British Standard Specification for Electric Cable Soldering Sockets. No. 91. 1926.

British Standard Specification for Portland-Blastfurnace Cement. No. 146. 1926.

British Standard Specification for the Electrical Performance of Industrial Electric Motors and Generators with Class A Insulation. No. 168. 1926.

British Standard Specification for the Electrical Performance of Fractional Horse-Power Electric Motors. No. 170. 1926.

British Standard Switchgear Equipments for Direct-Current Circuits when the Voltage does not exceed 660 Volts. No. 194. 1926.

British Standard Sections of Light Rails and Fishplates for use in Mines. No. 248. 1926.

British Standard Table of Cast Iron Flanges for Pipes, Valves, and Fittings for Gas. No. 253. 1926.

British Standard Specification for Asbestine for Paints. No. 255. 1926.

British Standard Specification for Interior Oil Varnish. No. 256. 1926.

British Standard Specification for Exterior Oil Varnish. No. 257. 1926.

British Standard Specification for Flatting or Rubbing Oil Varnish. No. 258. 1926.

British Standard Specification for Boiled Linseed Oil. No. 259. 1926.

British Standard Specification for Barytes for Paints. No. 260. 1926.

British Standard Specification for Brazing Solder. (Grades A and B). No. 263. 1926.

British Standard Specification for Hot Rolled Yellow Metal Plates, Sheet and Strip, excluding Condenser Plates and Ships' Sheathing. No. 264. 1926.

British Standard Specification for Brass Sheet and Strip for General Engineering Purposes. No. 265. 1926.

British Standard Specification for Best Brass Sheet and Strip. No. 266. 1926.

British Standard Specification for Cartridge Brass Sheet and Strip. No. 267. 1926.

British Standard Specification for Fixed Condensers for Radio Reception Purposes. No. 271. 1926.

British Standard Specification for Instrument Transformers. No. 81. 1927.

British Standard Specification for Graphic (Recording and Chart-Recording) Ammeters, Voltmeters, and Wattmeters. No. 90. 1927.

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British Standard Specification for Insulating Oils for Electrical Purposes, excluding Cables. No. 148. 1927.

British Standard Specification for the Electrical Performance of Transformers for Power and Lighting. No. 171. 1927.

British Standard Specifications for Overhead Line Wire Material (Non-Ferrous) for Telegraph and Telephone Purposes. Nos. 174 to 181. 1927.

British Standard Specifications for Galvanised Iron and Steel Wire for Telegraph and Telephone Purposes. Nos. 182 to 184. 1927.

British Standard Specification for Face-Plate Startors for Electric Motors (Direct Current). No. 246. 1927.

British Standard Specification for Face-Plate Rotor Startors for Electric Motors. No. 247. 1927.

British Standard Specification for Dimensions of Rivets ($\frac{1}{2}$ inch to $1\frac{3}{4}$ inch Diameter). (This Specification does not apply to Boiler Rivets). No. 275. 1927.

British Standard Specification for Flame-Proof Type Plug and Socket, Heavy Duty, 100 Ampere, for Voltages not exceeding 660. No. 279. 1927.

British Standard Specification for Blanc Fixe for Paints. No. 281. 1927.

British Standard Specification for Lead Chromes (Primrose, Lemon, Golden or Middle, and Orange) for Paints. No. 282. 1927.

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British Standard Specification for Vegetable Black for Paints. No. 286. 1927.

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British Standard Specification for Mineral Black for Paints. No. 288. 1927.

British Standard Specification for the Material for Colliery Tub Drawbars, Shackles, and Couplings. No. 291. 1927.

British Standard Dimensions for Wide Type Concentric Piston Rings for Automobiles. No. 5003. 1927.

British Standard Specification for Cast Iron Piston Ring Pots (Sand Cast and Chill Cast) for Automobiles. No. 5004. 1927.

Report on British Standard Nomenclature for Electrical Equipment for Automobiles and Motor Cycles. No. 5012. Divisions 6, 7, and 8. 1927.

British Standard Dimensions for Narrow Type Concentric Piston Rings for Automobiles. No. 5023. 1927.

Indexed List of British Standard Specifications and Reports. No. C.B. 2007. January, 1927.

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Bruce, S. M. The Financial Position of Australia. London. 1926. pph. From the Author.

Carnegie, D. The History of Munitions Supply in Canada, 1914-1918. London. 1925. From the Author.

Chestney, G. P. Lectures on Track Construction and Design. Calcutta. 1923. pph. McGlashan, J. Lectures on Harbour and Dock Engineering at the Port of Calcutta. Calcutta. 1926. From the Government of Bengal.

Dundee Chamber of Commerce. Year-Book for 1926. Dundee. From the Directors.

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Hadfield, R. Progress in the Development and Practical Application of Heat Resisting and Non-Corroding Steels. London. 1927. pph. From the Institute of Marine Engineers.

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Marine Department, New Zealand. Departmental Tables Governing the Safe Working Loads for Chains and Ropes. Wellington, New Zealand. 1926. pph. Safe Working Loads. Wellington, New Zealand. 1927. pph. From the Marine Department.

Nicol, G. Ship Stability and other Calculations. Glasgow. 1927. From the Author.

Primrose, J. S. G. Steel Furnace Crystals. Cleveland. 1927. pph. From the Author.

Report on Tabulating the Result of Heat Engine Trials, 1927. (3 Copies). London. 1927. From the Institution of Civil Engineers.

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Spanner, E. F. The Naviators. London. 1926. From the Author.

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Verein Deutscher Maschinenbau-Anstalten. Berlin. 1927. From the Association.

The Committee desire to thank cordially the donors of books and pamphlets to the Library.

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Albion, R. G. Forests and Sea Power: The Timber Problem of The Royal Navy 1652-1862. Cambridge, U.S.A. 1926.

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Andrade, E. N. da C. The Structure of the Atom. 3rd ed. London. 1927.

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Judge, A. W. The Testing of High Speed Internal Combustion Engines. London. 1924.

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Kari, A. The Design of Merchant Ships and Cost Estimating. London. 1927.

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Long, S. H. Navigational Wireless. London. 1927.

Mantell, L. The Theory and Practice of Carburation. London. 1921.

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Morrell, R. W. Oil Tankers. New York. 1927.

Munro & Jamieson's Pocket-Book of Electrical Rules and Tables. 22nd ed. London. 1927.

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Osborne, W. F. Power Plant Lubrication. New York. 1925.

Painton, E. T. The Working of Aluminium. London. 1927.

Parker, P. A. M. The Control of Water as applied to Irrigation, Power, and Town Water Supply Purposes. 2nd ed. London. 1925.

Plummer, T. H. Compressed Air and its Machinery. New Malden. 1925.

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Seaton, A. E., and Rounthwaite, H. M. A Pocket-Book of Marine Engineering Rules and Tables. London. 1927.

Shand, S. J. Useful Aspects of Geology. London. 1925.

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Tyrrell, G. W. The Principles of Petrology. London. 1926.

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The Institution Exchanges Transactions with the Following Societies, Etc.:—

American Philosophical Society, Philadelphia.

American Society of Civil Engineers, New York.

American Society of Naval Engineers, Washington.

Association des Ingénieurs sortis des Écoles Spéciales de Gand, Gand.

Association Technique Maritime et Aéronautique, Paris.

Barrow and District Association of Engineers, Barrow.

British Corporation Register of Shipping and Aircraft, Glasgow.

Bureau of Steam Engineering, Navy Department, Washington.

Bureau Veritas International Register of Shipping, Paris.

Chemical, Metallurgical, and Mining Society of South Africa, Johannesburg.

École Polytechnique, Paris.

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Engineering Institute of Canada, Montreal.
Franklin Institute, Philadelphia.
Institute of Marine Engineers, London.
Institute of Metals, London.
Institution of Automobile Engineers, London.
Institution of Civil Engineers, London.
Institution of Civil Engineers of Ireland, Dublin.
Institution of Electrical Engineers, London.
Institution of Engineers, Australia, Newcastle Branch, New South Wales.
Institution of Engineers, Australia, Sydney.
Institution of Gas Engineers, London.
Institution of Mechanical Engineers, London.
Institution of Mining Engineers, London.
Institution of Naval Architects, London.
Institution of Railway Signal Engineers, Derby.
Iron and Steel Institute, London.
Junior Institution of Engineers, London.
Liverpool Engineering Society, Liverpool.
Lloyd's Register of Shipping, London.
Manchester Association of Engineers, Manchester.
Manchester Literary and Philosophical Society, Manchester.
Manchester Municipal College of Technology, Manchester.
Mines Branch, Department of Mines, Ottawa.
Mining Institute of Scotland, Glasgow.
National Physical Laboratory, Teddington.
Norske Veritas Register of Shipping, Oslo.
North East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne.
Patent Office, London.
Royal Aëronautical Society, London.
Royal Canadian Institute, Toronto.
Royal Dublin Society, Dublin.
Royal Philosophical Society, Glasgow.
Royal Scottish Society of Arts, Edinburgh.
Royal Society of Arts, London.
Royal Society of Edinburgh, Edinburgh.
Rugby Engineering Society, Rugby.
Scientific Society of the Royal Technical College, Glasgow.
Smithsonian Institution, Washington.
Société d'Encouragement pour l'Industrie Nationale, Paris.
Société des Ingénieurs Civils de France, Paris.
Société Industrielle de Mulhouse, Mulhouse.
Society of Naval Architects and Marine Engineers, New York.
South Wales Institute of Engineers, Cardiff.
University of Cambridge, Cambridge.

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University of Illinois Engineering Experiment Station, Urbana.
University of Liverpool, Liverpool.
University of Sheffield, Sheffield.
University of Toronto, Toronto.
Victorian Institute of Engineers, Melbourne.
West of Scotland Iron and Steel Institute, Glasgow.

PUBLICATIONS RECEIVED PERIODICALLY IN EXCHANGE FOR INSTITUTION'S TRANSACTIONS:—

Weekly.

American Machinist.
American Marine Journal.
Autocar.
Automotor Journal.
Canadian Machinery.
Colliery Guardian.
Electric Railway and Tramway Journal.
Electrical Review.
Engineer.
Engineering.
Fairplay.
Flight.
Indian Engineering.
Iron and Coal Trades Review.
Journal of Commerce (Thursday issue).
L'Industria: Rivista Tecnico-Scientifica ed Economica.
Machinery.
Machinery Market.
Manchester Guardian Commercial.
Mechanical World.
Modern Transport.
Motor Boat.
Motor World.
Nautical Gazette.
Shipbuilding and Shipping Record.
Shipping World.
Syren and Shipping.
Times Engineering Supplement.

Fortnightly.

La Technique Moderne.

Monthly.

American Marine Engineering and Shipping Age.
American Motorship.
Association of Drop Forgers and Stampers.
British Engineers' Export Journal.
Bulletin Technique du Bureau Veritas.
City and Guilds (Engineering) College Journal—The Central.
Civil Engineering.
Cleveland Scientific and Technical Institution Bulletin.
Cold Storage and Produce Review.
Colliery Engineering.
Colville's Magazine.
Combustion.
Compendium of Commerce.
Compressed Air Magazine.
Concrete and Constructional Engineering.
Edinburgh Journal of Science, Technology, and Photographic Art.
Engineering and Boiler House Review.
Fuel Economist.
Gas and Oil Power.
Gas Engineer.
Indian and Eastern Engineer.
Indian and Eastern Motors.
Indian and Eastern Railways.

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Industrial Management.
Irish Electrician.
Iron and Steel of Canada.
Journal of Chamber of Commerce, Aberdeen.
Journal of Chamber of Commerce, Belfast.
Journal of Chamber of Commerce, Edinburgh.
Journal of Chamber of Commerce, Glasgow.
Journal of the Royal Technical College, Glasgow.
Marine Engineer and Motorship Builder.
Merchant Shipping Review and Empire Trade Gazette.
Metropolitan Vickers Gazette.
Motor Ship.
Nautical Magazine.
Oil Engineering and Technology.
Popular Science Monthly.
Science Abstracts.
Shipbuilder.
South African Engineering.
Sperryscope.
Tramway and Railway World.

Bi-Monthly.

Marine Engineer Officers' Magazine.

Quarterly.

The M. & C. (Mavor & Coulson) Apprentices' Magazine.

The Library and Reading-Room are open for the use of Members, Associate Members, Associates, and Students.

The Portrait Album lies in the Library for the reception of Members' Portraits. Members are requested when forwarding Portraits to attach their Signatures to the bottom of Carte.

The Library Committee are desirous of calling the attention of Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to the Library.

As arranged by the Council, a Register Book for Students lies in the Library for the inspection of Members, the object being to assist students of the Institution in finding suitable appointments.

PERCY A. HILLHOUSE, D.Sc.,
Hon. Librarian and Convener.

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REPORTS OF INSTITUTION'S REPRESENTATIVES ON VARIOUS BOARDS.

The Institution was represented on the following boards and committees:—

Advisory Committee for the William Froude National Tank, by Prof. Percy A. Hillhouse, D.Sc.;

Board of Governors of the Glasgow and West of Scotland Commercial College, by Prof. A. L. Mellanby, D.Sc.;

Board of Governors of the Glasgow School of Art, by Mr. Laurence MacBrayne, O.B.E., M.A.;

Board of Governors of The Royal Technical College, Glasgow, by Mr. Harold E. Yarrow, C.B.E.;

Board of Trade Consultative Committee, by Mr. A. J. Campbell, Mr. J. Howden Hume, Mr. S. J. Pigott, and Mr. S. B. Ralston;

British Corporation Technical Committee, by Prof. Percy A. Hillhouse, D.Sc., and Mr. W. W. Marriner;

British Engineering Standards Association: Panel 10/1/9, Bright Bolts and Nuts, by Eng.-Capt. W. Onyon, R.N. (ret.), M.V.O.

British Engineering Standards Association: Panel 10/1/13, Black Bolts and Nuts, by Eng.-Capt. W. Onyon, R.N. (ret.), M.V.O.;

British Engineering Standards Association: Sectional Committee on Cast Iron, by Mr. R. D. Moore, B.Sc.;

British Engineering Standards Association: Sectional Committee on Gears, by Mr. N. O. Fulton;

British Engineering Standards Association: Sectional Committee on Machine Parts, their Gauging and Nomenclature, by Mr. J. Howden Hume;

British Engineering Standards Association: Sectional Committee on Petroleum Products, by Mr. A. J. T. Taylor;

British Engineering Standards Association: Sub-Committee on Screw Threads, by Mr. W. W. Marriner;

British Engineering Standards Association: Sub-Committee on Steel Flanges for Hydraulic Pressure, by Mr. T. A. Hayward;

Institute of Metals: Corrosion Research Committee, by Mr. James G. Weir, C.M.G., C.B.E.;

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Institution of Civil Engineers: Committee on Tabulating the Results of Heat-Engine Trials, by Prof. A. L. Mellanby, D.Sc., Mr. R. B. Mitchell, Mr. James Richardson, B.Sc., and Eng.-Com. W. McK. Wisnom, R.N.;

Joint-Committee on the Organisation of Classes in Science and Technology, by Mr. R. D. Moore, B.Sc.;

Lloyd's Technical Committee, by Mr. George Brown, Mr. James Brown, C.B.E., Mr. William Miller, O.B.E., and Mr. F. E. Rebbeck.

The following are reports from these representatives:—

William Froude National Tank.

Two meetings of the Committee were held in London, and one at the Tank, when the buildings and apparatus were inspected.

New apparatus was installed, and self-propelled models can now be tested with one, two, or four propellers; these tests give quasi-propulsive coefficients, but not wake or thrust deduction fractions. Stream lines around the model can now be lined off by means of small vanes or "flags" indicating within the model, and the best line for bossings determined.

The work accomplished includes hull and propeller tests on all classes of vessel, and improvements in form and propellers were effected in many cases. The air resistance of a destroyer was tested in the wind tunnel; eleven seaplanes were also tested. A flat disc and an airship form were tested both in air and in water, and the results compared. Fairly good results were obtained with the disc, but the comparison in the case of the airship was somewhat indefinite. Experiments were carried out on a small screw at three different depths of immersion, and apparatus is being made to enable a 1·12-foot propeller to be similarly tried. An experiment was made to measure the towing force exerted by a tug on the river Thames, and barge forms were under consideration to find out if their resistance could be reduced.

The Superintendent visited the tanks in Paris, Spezia, and Vienna, and reported on their work and equipment. A number of trial trips were attended, and their results analysed. In future a fee of £20 is to be charged for such work, unless the results are expected to be of general interest and value. The

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trials attended include those of the "Ambuscade," "Port Huon," and "Empress of Australia." In the two latter vessels, inward-turning screws were adopted with good results, the propulsive coefficient being improved, and no adverse effect on steering experienced. Several Atlantic voyages were made by a member of the staff, and, with the kind co-operation of the owners of the vessels, records were made of wind and waves and of their effects on the ships.

The programme of work ahead includes experiments on tugs, the air resistance of superstructures, the stopping and backing power of propellers, the manœuvring of a fine-lined twin-screw vessel with unbalanced rudder, self-propulsion in rough water, the calculation of wave resistance, and check tests in the tank.

Glasgow and West of Scotland Commercial College.

The most notable new classes dealt with the subjects of Cost and Factory Accounting, Commercial Problems of Motor Transport, Railway Operating, Property Management, Economics for the Stockbroker and Banker, and Sales Organisation. A class on Market Research, which is being instituted, should be of special interest to engineers. The suppression of the advanced class in Accounting, in favour of the new University Chair on the same subject, explains a decrease of 80 in the number of students for session 1926-27, which amounted to 1,970 as compared with 2,050 in 1925-26.

A central site has now been acquired in Pitt Street for the new College building, and the Governors hope to enlist the active co-operation of all interested in commercial education, in order to complete the sum required for the Building and Endowments Fund.

The Glasgow School of Art.

The number of students attending during the session was 1,332, an increase of 58 on the previous session. A new feature was a class for Freehand Drawing, Lettering, and Perspective, which was attended by 70 engineers, junior and apprentice draughtsmen. There were 63 applicants for the

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School Diploma, of whom 57 were successful. Grants for maintenance are made by the "Haldane" Trust, the Merchants' House, and Education Authorities, to a total of £2,534. The School extension scheme has now been launched, and a sum of £35,000 is aimed at. Donations paid and promised to date amount to about £20,000, and a grant of £7,500 from the Scottish Education Department can be claimed if the balance of £8,000 required to complete the scheme is subscribed.

Royal Technical College.

The record of the session 1926-27 contains no outstanding event, but engenders the hope that the depression in the great industries with which the College is allied has passed its lowest ebb. The condition of the engineering, shipbuilding, mining, and metallurgical industries has always been reflected in the numbers of regular students attending the College, and, after four sessions of decreasing numbers, the past session showed no further loss, but a slight increase on the figures for 1925-26. The following comparative table is, therefore, reassuring:—

	1925-26.	1926-27.
Day students - -	895	934
Evening students - -	3,254	3,235
	4,149	4,169

The numbers attending the classes which form the particular province of the College in the field of evening work show no diminution, and still tax the extensive laboratory accommodation available. Some indication of the exceptional range and standard of the evening classes is given by the facts that 123 graduates of the Universities of Glasgow, Edinburgh, Aberdeen, St. Andrews, London, Leeds, Wales, and Bombay were enrolled last year, and that 2,258 of the students were 21 years of age or over, of whom 458 were 31 or over.

The degree of D.Sc. of Glasgow University was conferred upon one student, the degree of Ph.D. upon three students, the degree of B.Sc. upon 32 students who had taken the whole of their courses in the College, and upon 19 others who had

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also attended College classes. Of these, 16 graduated in applied chemistry, including metallurgy; 33 in engineering; and two in pure science. In addition, four students graduated B.Sc. in the University of London. Thirty-two students were admitted to the Associateship of the College, following upon four years of satisfactory work, and 28 were granted the diploma.

Research was actively prosecuted over a wide field. The subjects under investigation included the creep of metals; the influence of high temperatures on metals; the characteristics of impact testing; the influence of blade, width, angle, and curvature upon the losses occurring within turbine-blade passages; heat transmission and its bearing on superheater design; and losses in fluid flow and characteristics of high-speed jets.

Board of Trade Consultative Committee.

A complaint was presented to the Committee concerning the large size of fire engine required to conform with the Instructions concerning fire-extinguishing appliances in steam and motor passenger ships, and the space required to house such plant. The Marine Department advised that the tanks for froth installation apparatus are usually erected in some cool place, often on the open boat-deck, where the head thus obtained was available for rapid discharge of the froth into the boiler room. An additional advantage was that such an arrangement entailed no encroachment on valuable space, and any loss of space would probably be fully compensated for by the gain in cargo space through the use of double-bottoms for oil tanks.

During the year the Committee received several recommendations for improvements in future editions of existing Instructions issued by the Board. Chief among these were:—

A suggestion that the Instructions relating to the Survey of Life-Saving Appliances, 1926, should be extended to embrace boats of greater length than 30 feet and of greater capacity than for 68 persons, say, boats having a capacity for about 100 persons. Such a suggestion is not novel. Several

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boats 30 feet long to carry some 80 passengers were previously passed, but the Board's general attitude then was not to encourage very large boats, owing to the lessening of boat accommodation should one of these large boats be damaged. There were also practical difficulties in the handling, manning, and sending away of such boats in the event of emergency.

A firm of boilermakers suggested that the Board, in order to obviate certain delays which they had experienced, should consider a system similar to that employed by Lloyd's, under which engineering firms, forgemasters, boilermakers, and others sign a yearly undertaking to pay at stated periods fees incurred by them during these periods. The Committee informed the firm in question that arrangements are already in force whereby firms may open a deposit account, against which the Board of Trade survey fees and expenses incurred are charged. Full particulars of the system may be obtained from the superintendent of the local Mercantile Marine Office.

No further developments took place in connection with the necessity for launches and other small craft having passenger certificates, but the Committee expressed their willingness to discuss with the Board methods by which the provisions of the Merchant Shipping Acts, with regard to passenger certificates, may be applied to these small craft, with a minimum of inconvenience to those concerned, especially to those who in perfectly good faith have hitherto thought that such small craft did not come within the scope of the Acts.

British Corporation Technical Committee.

Probably the matter of most general interest during the session was an evidence of growth in the demand for mild steel of higher tensile strength than the present standard material.

The Society made a notable movement during the past year, as is indicated by the changing of its name—The British Corporation Register of Shipping and Aircraft. An Aviation Committee was formed, and in conjunction with six other societies an International Register Book of Aircraft is in course of preparation. Portents in relation to the work and constitution of

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this Institution might perhaps be read into such an alliance between the technical work of shipbuilding and aeronautics.

British Engineering Standards Association: Sectional Committee on Machine Parts.

Dimensions of Bolts and Nuts. As the result of discussions on the Continent and in America upon the subject of the adoption of bolts and nuts with reduced widths across flats and thicknesses, a conference was convened to obtain the feeling of British manufacturers and users. At this conference representatives of a very large number of Government Departments and branches of industry were present, and it transpired at the meeting that there was a growing demand for a Whitworth bolt having a head and nut of the dimensions of the corresponding nominal B.S.F. size. It is proposed to include such a series in the British standards, and a committee is to meet very shortly to prepare the draft tables.

Screw Threads. The extensive investigation carried out by the National Physical Laboratory on the screw threads of a large number of commercial bolts and nuts, collected from manufacturers and users in many branches of industry throughout the country, was completed early in the year. A comprehensive report submitted by the Laboratory has received the consideration of the B.E.S.A. Committees on Screw Threads, and the present Standard Tables of B.S.W. and B.S.F. screw threads are receiving consideration with a view to their revision. Hand in hand with this work, a further committee has been engaged in drawing up standard tolerances for commercial taps.

Black Bolts and Nuts. A draft specification for black cup and countersunk bolt-heads has received further consideration in connection with comments received, and standards for black washers to be used in conjunction with these bolts have been drawn up and added to the specification. The complete draft is now being submitted to the superior Committee prior to publication.

Keys and Keyways. A new edition of the B.S. Specification No. 46 for Keys and Keyways is in course of preparation. In

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addition to the plain square and rectangular parallel keys, the dimensions of which remain unaltered, the new specification will include taper keys, both plain and gib-head, tangential keys, peg keys, woodruff keys, splines, serrations, and taper pins, and also a section dealing with the standard nomenclature for the various forms of keys in common use.

Twist and Straight Flute Drills. With the co-operation of the Government Technical Co-ordinating Committee, a B.S. specification for twist and straight flute drills was prepared. The specification, which includes tables of standard dimensions for the various types of drills in common use, and performance tests with which the finished twist drills must comply, is now ready for submission to the various technical institutions and trade organisations interested for criticism.

Reamers. When the B.S. Specification No. 122 on Milling Cutters and Reamers was drawn up and issued in 1920, the Report on B.S. Limits and Fits for Engineering (No. 164—1924) had not been completed, and there had been no opportunity of correlating the reamer limits given in Specification No. 122 with those for the standard holes. The tolerances for the reamer diameters have now been reconsidered. It was not found commercially practicable to standardise reamer limits to suit each of the standard holes provided for in B.S. Report No. 164. A compromise, therefore, had to be effected, and the reamer limits given in the revised tables were chosen as likely to meet the majority demand from users working to the standard U unilateral holes and the Y bilateral holes. The revised tables were submitted to the various technical institutions and trade organisations interested, and met with general approval.

Rolled and Drawn Steel Sections for the Production of Machined Parts. A revised edition of B.S. Specification No. 32 for Steel Bars for the Production of Machined Parts was prepared, and is ready for publication. The principal alterations embodied in this edition are as follows:—

1. The Bessemer basic process for the manufacture of the steel has been eliminated, and the electric process has been included.

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2. A minimum carbon content has been specified for Grades 1 and 2 steels, and omitted from Grade 3 (free cutting) steel.
3. The minimum tensile strength of Grade 3 (free cutting) steel has been reduced to 28 tons per square inch for bright bars, and to 26 tons per square inch for other finishes. In all three grades provision has been made for the higher precentage elongations obtainable from other than cold rolled and drawn bars.
4. Round bars above 5 inches diameter and square bars above 5 inches width across flats have been standardised in definite steps of $\frac{1}{4}$ inch.
5. Bright hexagon bars corresponding to Numbers 1, 2, 3, and 4 B.A. bolt sizes have been included, and the hexagon bars corresponding to $\frac{13}{16}$ inch, $\frac{15}{16}$ inch, and $1\frac{7}{8}$ inch bolt sizes have been omitted, as these three sizes are no longer included in the British Standard Whitworth and British Standard Fine Screw Thread Tables.

It was not found practicable to include standard tolerances for the black bars, in view of the differing purposes for which the bars are used. For example, tolerances which are commercially suitable for bars for the direct production of machined parts, are regarded as too wide for the production of bright drawn bars from the black rolled material. For a similar reason, standard tolerances for blue bars were omitted.

British Engineering Standards Association: Sectional Committee on Petroleum Products.

No meeting of this Sectional Committee took place during the past twelve months, largely because no specific suggestions for the revision of the B.S. Specifications No. 209, Fuels for Heavy-Oil Engines (petroleum and shale oils), and No. 210, Classification of Pure Mineral Lubricating Oils, were received.

The Sectional Committee is represented by several members on the Sub-Committee on Insulating Oils for Electrical

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Purposes, which published a revision of B.S. Specification No. 148, Insulating Oils for Electrical Purposes. The discussions regarding the revision of this specification were spread over several years, there being a large number of technical and commercial considerations to be carefully taken into account, necessitating considerable research and consultation with technical and trade organisations. The representatives of the Petroleum Sectional Committee on the Sub-Committee dealing with this specification took a very active part in the work, some of them also assisting by attending meetings of the International Electrotechnical Commission at which the question of insulating oils was discussed. Such a meeting was held in Italy in September, 1927, when the British delegation contributed very usefully to the discussions.

British Engineering Standards Association: Sub-Committee on Screw Threads.

The progress made by this Sub-Committee is referred to in the report of the Sectional Committee on Machine Parts.

British Engineering Standards Association: Sub-Committee on Steel Flanges for Hydraulic Pressure.

During the year, flanges varying from $\frac{3}{4}$ inch to 10 inches were considered, and drawings of these were made and submitted. After many modifications, it was decided to adopt pairs of flanges for each size, each pair to be submitted to a hydraulic test for the purpose of ensuring the correct dimensions and sections of the material.

Institute of Metals: Corrosion Research Committee.

Under the direction of the Committee, Mr. May continued the investigation of a number of problems connected with the corrosion and protection of condenser tubes. The greater part of the work carried out during the year was on the formation of protective films and scales, since it is becoming more clearly realised that the good behaviour of brass tubes, under working

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conditions, frequently depends to an important extent on the presence of such films. Special attention was given to the influence of iron compounds on film formation, as the presence of iron appears to be a significant feature in the more important types of film which are formed naturally. Attempts to produce such films artificially showed that their formation is more complicated than appear at first sight. It was found that the presence of other substances may have a profound effect. If other conditions are suitable, the presence in the liquid of as little as one part per million of certain colloidal materials may be the deciding factor between a good or a bad film.

Considerable success was attained in the formation of resistant films in certain silicate solutions. Films of this type were produced, and they appear to differ from the films already mentioned in being resistant to deposit attack. The investigation of these films is being actively continued. Valuable information on the deposition of films and scales was very kindly supplied by the engineers in charge of certain power plants.

Further work was carried out on the electrical differences which may be set up, under certain conditions, between the tubes and tube plates of a condenser. The results are of much interest, since they provide a simple explanation of a number of actual cases of condenser-tube corrosion, for which there was previously no satisfactory explanation.

There was a good demand during the year for the revised pamphlet prepared by the Committee entitled "Notes on the Corrosion and Protection of Condenser Tubes."

Institution of Civil Engineers: Committee on Tabulating the Results of Heat-Engine Trials.

The Report of this Committee was presented to the Council of the Institution of Civil Engineers, who adopted it and authorised its publication. They also decided to form a standing Committee, to be called "The Heat-Engine Trials Committee." Messrs. William Clowes & Sons were authorised to publish the Report, under the authority of the Council of the Institution of Civil Engineers, at 5s. per copy.

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The Joint-Committee on the Organisation of Classes in Science and Technology.

The scheme for the closer connection of the evening science classes held in affiliated areas is controlled by the Joint-Committee, and extends throughout the districts of the Education Authorities of Glasgow and of the counties of Ayr, Clackmannan, Dumbarton, Dumfries, Lanark, Renfrew, Stirling, and Wigtown. Last session the affiliated classes were conducted in over one hundred centres, with an enrolment of 6,063 students, exclusive of preparatory classes. Provision was made for students in all branches of engineering, naval architecture, coal mining, architecture and building, chemistry and metallurgy, textile manufacture, and bakery. The instruction provided in the classes leads to higher work in the Royal Technical College in these various facilities.

In April of this year the Education Authority of Glasgow withdrew from the scheme of affiliation with the College, the reason given for this withdrawal being that the purpose for which the scheme was formed had now been served. This withdrawal was very much regretted by the Joint-Committee.

Lloyd's Technical Committee.

The Committee considered amendments to the Society's requirements regarding the carriage and burning of oil fuel. These amendments were proposed with a view to preventing damage to cargo through contamination with oil fuel, and are now embodied in the Rules.

Consideration was also given to amendments to the Rules relating to the riveting of the side frames to the shell plating in cargo ships.

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OBITUARY.

Members.

JOHN ANDERSON was born at Selkirk, on 4th July, 1866, and was educated locally. After serving his apprenticeship with Messrs. Bathgate, engineers, Selkirk, he found employment with Messrs. Watson, Laidlaw & Co., Glasgow. In December, 1892, he went to Honolulu, where he acted as engineer on the Kealia Sugar Plantation, on the island of Kauai. Returning to Glasgow in 1903, he was appointed works manager to Messrs. Watson, Laidlaw & Co., and remained in this capacity until his death, which took place in a nursing home on 13th December, 1927.

Mr. Anderson joined the Institution as a Member in 1917.

ALFRED WILLIAM BAIRD, a director of Messrs. Kelvin, Bottomley & Baird, Ltd., was accidentally drowned in the River Tay, at Dundee, on 10th January, 1928, while transferring from the vessel "British Faith" to a tug in mid-stream. Mr. Baird, who was 65 years of age, was recognised as a leading authority on ship compasses, and had been associated with his firm for over 40 years. He belonged to Glasgow, and was educated at Glasgow Academy. As a young man he was personal assistant to the late Lord Kelvin (then Sir William Thomson), having charge of the department of the works concerned with the great scientist's navigational instruments and inventions. In 1901, when the firm of Kelvin & James White was made a private joint-stock concern, Mr. Baird was admitted a director, and subsequently the company became Kelvin, Bottomley & Baird.

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Mr. Baird joined the Institution as an Associate in 1907, and was elected a Member in 1916.

WILLIAM REID BELL was born at Edinburgh in 1857, and was educated at the late Dr. Hamilton Bryce's Collegiate School in the same city. He served his pupilage from 1874 to 1878 with Messrs. Bell & Miller, Glasgow, and was afterwards employed as assistant to Mr. J. Watt Sandeman until his departure in 1879 for New Zealand, where he laid out the Government Railway Workshops at Christchurch. From 1880 to 1881 he was general manager of the Springfield Colliery, and thereafter was engaged under Mr. Charles Napier Bell on the Christchurch drainage works. Two years later he became Railway Surveyor to the Tasmanian Government, and in 1885 designed and built the first Emu Bay Breakwater. Returning to Glasgow in 1888 as chief assistant to Messrs. Bell & Miller, he designed important hydraulic and harbour works, and as resident engineer for the Glasgow Corporation constructed, to Messrs. Bell & Miller's designs, the Great Western Road Bridge. He went to South Africa in 1893, and was engaged in hydraulic engineering and mine management on the Witwatersrand and Eastern Transvaal. From 1898 to 1900 he had charge of various works for the Durban Corporation, and erected an iron pile lighthouse for the Portuguese Government at Delagoa Bay. On the conclusion of the Boer War, during which he held a commission in the Railway Pioneer Regiment, he was appointed irrigation engineer to the Transvaal Land Department, and later became sewerage engineer for the city of Johannesburg, in which position he constructed reticulation and outfall works to the value of £100,000.

Returning to Australia in 1908, he was engaged in the preparation of reports on new lighthouses for the Federal Government, and on designs for the power and other plant of the Government Cordite Factory, Maribyrnong. Two years later

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he was appointed hydraulic engineer to the Tasmanian Government, and in June, 1911, took up the position of chief engineer to the Marine Board of Burnie and Table Cape, where he designed and built the second Emu Bay Breakwater on the sloping block system, the outstanding feature of which was the use of specially shaped blocks 29 feet in length and weighing 70 tons each. Subsequently, he was engaged in private practice, and was adviser to the Australian Defence Department on the lighting of Simpson's Haven and Blanche Bay, in the late German New Guinea. Until his death, which took place at Melbourne, Australia, on 28th July, 1927, he was a partner in the firm of Messrs. J. M. & H. E. Coane & Bell, Melbourne.

Mr. Bell joined the Institution as a Member in 1889.

William Ashcombe Chamen died at Rhoose, Wales, on 13th August, 1928. He was a native of New Cross, Kent, where he was born in 1864, and was educated at the Forest School, Walthamstow, Essex, a seminary connected with King's College, London. He underwent his mechanical training at the works of Messrs. James Gibbs & Co., Cattedown, Plymouth, and when only a youth became associated with Messrs. Crompton & Co., electrical engineers, with whom he remained for 17 years. During that period he was responsible for installing the arc lighting at King's Cross Station, London. He then represented the firm in Munich and Italy, and laid down several mill-lighting installations in Tuscany. On returning to England he was entrusted with the lighting of the Royal Courts of Justice, one of the first installations of incandescent lighting in the Kingdom. He was in charge of the machinery at the Forth Bridge Works, after which he designed a central station for Barry Dock ,and constructed the electric railway on Southend Pier. Other contracts comprised the erection of generating plant for the towns of Dewsbury and Yarmouth, the lighting of Birkenhead and the South Kensington Museum.

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In 1896 he was appointed electrical engineer to the City of Glasgow, and during his period of service constructed two large generating stations, one at Port-Dundas and the other at St. Andrew's Cross. On leaving Glasgow in 1905 he joined the firm of Messrs. Bramwell & Harris, London, who were at that time laying out the equipment of several electrical undertakings, including that of the South Wales Electrical Power Distribution Co. He subsequently joined the latter firm as engineer and general manager, a position which he held until the end of 1927.

Mr. Chamen joined the Institution as a Member in 1888.

JAMES BUCHANAN CRAWFORD was born at Govan in March, 1872, and was educated at the High School and the University, Glasgow, graduating B.Sc. in 1894. On the completion of his apprenticeship with Messrs. J. & G. Thomson, Clydebank, he spent six months with Messrs. S. McKnight & Co., Ayr, and thereafter joined his father at Kinghorn Shipyard. In 1900 he obtained an appointment as naval architect to Messrs. William Hamilton & Co., Ltd., Port-Glasgow, and remained in that position till his death, which took place at his home in Gourock on 13th June, 1928. He took an active interest in the work of the British Engineering Standards Association, and served as chairman on several panels.

Mr. Crawford joined the Institution as a Member in 1919.

JAMES ANNANDALE DENHOLM was born at Chirnside, Berwickshire, on 26th August, 1868, and served his apprenticeship with his father, who was a millwright and engineer at Chirnside. For a short time he was employed in the North British Locomotive shops in Edinburgh, and then spent two years as an engineer on board ship. About 30 years ago he entered the service of Messrs. William Beardmore & Co., Ltd.,

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Dalmuir, and, after passing through various grades, was appointed works manager in 1913, in which capacity he remained until his death. His energies were mainly devoted to the service of his firm, but he was also keenly interested in the engineering societies of the West of Scotland, and was a valued member of the Executive Council of the Foremen's Mutual Benefit Society. He died at Dalmuir on 24th May, 1928.

Mr. Denholm joined the Institution as a Member in 1918.

Patrick Dunlop Donald, engineer to the Clyde Navigation Trust, died in a nursing home at Glasgow, on 3rd July, 1928, in his sixtieth year. He received his preliminary technical training at Glasgow University, after which he served as a pupil with Mr. John Strain, Glasgow, who had been engineer for such important works as the Lanarkshire and Ayrshire Railway and the Ardrossan Harbour Extension. This period was followed by three years with Messrs. Strain & Robertson, for whom he acted as assistant resident engineer at the Ardrossan Harbour, and also as resident engineer in connection with Railway work near Edinburgh. Another two years were spent on surveys and preliminary work for Edinburgh's scheme for augmenting its water supply by drawing on the Talla Water, a tributary of the Tweed. In addition to such wide experience at home, Mr. Donald was for six years engaged in railway work in the Federated Malay States. In 1903 he joined the Clyde Navigation Trust, and for ten years was leading office assistant to Mr. W. M. Alston, who was then chief engineer. In 1913 he became assistant chief engineer, and five years later succeeded Mr. Alston as chief engineer.

Mr. Donald was an engineer of high professional qualifications, and the manner in which he handled the extensive operations of the Trust showed that he was equally efficient as an administrator. During the ten years he was chief

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engineer he carried out much important work in connection with riverside quays, but his greatest achievement was the extensive system of docks at Shieldhall, for which he designed the plans.

Mr. Donald joined the Institution as a Member in 1917.

William Russell Fergusson died at his residence at Taynuilt, Argyllshire, on 19th December, 1927. Born at Whiteinch, Glasgow, on 18th February, 1863, he was educated at Glasgow Academy, Clifton Bank, St. Andrews, and Glasgow University. Following the profession of his father, who was a well-known shipbuilder, he served his apprenticeship with Messrs. Barclay, Curle & Co., and then worked for a time with Messrs. Robert Duncan & Co., Port-Glasgow. Soon after, he returned to the scene of his apprenticeship, and by sheer force of personality and efficiency eventually became a director in 1884, when the business became a limited company. In 1900 he was appointed managing director, and, on the death of Mr. James Gilchrist in 1917, was elected chairman, which position he held until a few months before his death. The company amalgamated with Messrs. Swan, Hunter & Wigham Richardson, Ltd., Wallsend-on-Tyne, in 1913, and Mr. Fergusson was appointed a director, but was compelled to resign from the post through ill-health. He took a close personal interest in the affairs of the company, especially in regard to the development of the internal-combustion engine for marine purposes, and was recognised as an authority on the commercial side of shipbuilding and marine engineering.

Mr. Fergusson joined the Institution as a Graduate in 1881, and was elected a Member in 1895.

Donald Burns Gebbie passed away at Ayr on 11th August, 1928. Mr. Gebbie, who was well known as a naval architect

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and shipbuilder, was about 45 years of age, and obtained his early training on the north-east coast of England, but migrated later to the Clyde, where he served with Messrs. Russell & Co., Port-Glasgow, Messrs. Harland & Wolff, Ltd., Govan, and Messrs. D. & W. Henderson & Co., Ltd., Partick. Shortly before the end of the war he became general manager of the shipyard at Garston, near Liverpool, belonging to Messrs. H. & C. Grayson. In 1921 he retired from this position, and started a private consulting practice in Liverpool. Soon afterwards, however, he accepted an invitation to become general manager of the works of the New Waterway Shipbuilding Co., Rotterdam. From this position he transferred his services in 1925 to the Furness Shipbuilding Co., who had laid out a new shipyard at Haverton, Hill-on-Tees. He subsequently returned to Holland to the service of Messrs. P. Smit, jun., Rotterdam, but was compelled by a breakdown in health to retire from this firm last year. Mr. Gebbie was the designer, in co-operation with Prof. T. B. Abell, of Liverpool University, of a method of hull construction known as the "G.A." system, which has been applied to a considerable number of vessels.

Mr. Gebbie joined the Institution as a Member in 1916.

Thomas Hodge died suddenly at Sheffield on 10th January, 1928. He was born at Pollokshields, Glasgow, on 7th April, 1872, and received his early education at Burntisland, afterwards attending the Collegiate School, Queen's Park, and the Technical College, Glasgow. He served his apprenticeship as a marine engineer with Messrs. Alley and McLellan, Ltd., Glasgow, with whom he remained for a period of nine years. Subsequently he gained valuable experience in the design of locomotives and passenger and freight cars while in the service of Messrs. Neilson Reid & Co., Glasgow, and Messrs. Gregory Eyles & Waring, London. In 1916 he entered the employment of Lloyd's Register of Shipping, and for six years was engaged in the inspection of steel plates, forgings, castings, tubes, etc.,

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at Pittsburgh. He also inspected and tested complete marine turbines at the works of the Westinghouse Co. and the Ridgway Dynamo and Engine Co., respectively, and supervised the construction of narrow-gauge locomotives at the works of the H.K. Porter Co., Pittsburgh.

Mr. Hodge joined the Institution as a Member in 1911.

CHARLES PULLAR HOGG was a native of Forfarshire, having been born in the parish of Tannadice in 1848. He was educated at Forfar Academy, and after an early training with Mr. Robert Blackadder, at that time surveyor for the Strathmore Estates at Glamis, he came to Glasgow, and distinguished himself at the University, being awarded the James Walker Prize, in 1870, by the votes of his fellow-students in Prof. Rankine's civil engineering class. He gained further experience with the Caledonian Railway Co., and afterwards joined the staff of the late J. F. Blair, under whom he was engaged in the construction of the City of Glasgow Union Railway, and as resident engineer in the construction of St. Enoch Station. In 1876 he entered into partnership with the late Mr. William Crouch, under the firm name of Crouch and Hogg. The firm acted as engineers for numerous important works throughout Scotland, including bridges over the Clyde at Rutherglen and elsewhere, the Lochearnhead and Comrie Railway, and Arbroath Water Works. Later, Mr. Hogg, in partnership with two of his sons, was responsible for many water supply and drainage schemes, a notable example being the main drainage scheme recently completed for Dunfermline. In the course of his career, he appeared frequently as an expert witness before the Courts and Parliamentary Committees. He died at London on 8th November, 1927, in his eightieth year.

Mr. Hogg was elected a member of the Institution in 1880, and throughout his long connection with the Institution maintained a keen interest in its affairs. He was a Member of Council for sessions 1883-5, 1888-90, 1893-5, and 1903-6, a

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Vice-President for sessions 1885-7 and 1906-9, and President for session 1909-10. When the Institution's present premises were built in 1907-8, Mr. Hogg, who was peculiarly fitted for the position, was appointed Chairman of the Building Committee, and his time and valuable professional services were freely and unstintingly given to the work intrusted to him.

HAROLD DRINKWATER JACKSON was a native of Castletown, Isle of Man, and received his early education at King's School, Cheshire. On coming to Glasgow, he served his apprenticeship with the Fairfield Shipbuilding and Engineering Co., Govan, and afterwards studied at Glasgow University. Before he had finished his course, however, he was asked by Prof. Barr to accept a post in the business which the latter commenced in Glasgow, and now well known as Messrs. Barr & Stroud. Later he became a partner, and when the company was formed he was appointed a director. For the last seven years he held the position of managing director. He died, after a brief illness, at his home, Baldernock House, Milngavie, on 14th January, 1928, at the age of 57 years. In Glasgow he was identified with the Chamber of Commerce, and occupied a seat on the Executive Committee of the North-West Engineering Trades Employers' Association.

Mr. Jackson joined the Institution as a Graduate in 1891, and was elected a Member in 1898.

CHARLES ALBERT KNIGHT, for many years a director of Messrs. Babcock & Wilcox, Ltd., died in London on 6th June, 1928, aged 75 years. He was really the pioneer in this country of the water-tube boiler, having come from the United States in 1881 as European Manager of the Babcock & Wilcox Co., of New York. He carried on the business from Glasgow, but after a few years the foreign business extended so rapidly that

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it was decided to open a London office, and in 1891 the firm was transferred into a limited company, Mr. Knight acting as managing director jointly with the late Sir James Kennal. He resigned from this position in 1898, but remained an active director of Messrs. Babcock & Wilcox, Ltd., and all the associated companies, up to the time of his death. During the period he was in Glasgow, Mr. Knight took a keen interest in the volunteer movement, and for a number of years was a captain in the 5th Battalion H.L.I.

Mr. Knight joined the Institution as a Member in 1885.

ANDREW LAMBERTON was born at Paisley on 13th July, 1853, and died at Blairtummock, Easterhouse, on 23rd August, 1928. He learned the practical side of engineering first at Messrs. A. F. Craig & Co.'s Caledonia Engine Works, Paisley, and afterwards with Messrs. John Elder & Co. (now Fairfield Shipbuilding and Engineering Co.). In 1880 he went to Coatbridge, and founded the firm which bears his name. Devoting himself to the design and manufacture of iron and steel works plant, he soon became eminent in his profession, and designed and manufactured a very large number of the most important steel plants in Scotland and England.

He took a very prominent part in the work of the Iron and Steel Institute, of which he was a Vice-President, and in 1917 was awarded the Bessemer Gold Medal by a unanimous vote of the President and Council of that body, "In recognition of his eminent services in the advancement of mechanical engineering as applied to the manufacture of iron and steel."

He also took a considerable part in public life, being for many years a member of the Coatbridge Town Council and a Justice of the Peace for the County of Lanarkshire. For a number of years he was President of the North-West Lanarkshire Unionist Association.

Mr. Lamberton joined the Institution as a Member in 1897.

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CHARLES COXHEAD LINDSAY, who for many years practised as a consulting engineer in Glasgow, died at his home in Regent's Park, London, on 2nd January, 1928. Born in London on 29th December, 1845, he received his early education at a school in Tipperary and afterwards at Galway College. He then became a pupil with Messrs. W. & A. McOnie, Glasgow, and on completing his apprenticeship in 1867 returned to Ireland to attend engineering classes at Queen's College, Belfast. For two years he was on the staff of Sir John Macneil, and assisted in the completion of the Belfast Central Railway and works of a similar character. In 1870 he returned to Glasgow to take up a responsible position in the business of Messrs. Storry & Smith, who, at that time, were amongst the foremost engineering firms in the city. While in their employ he carried out improvements at Irvine Harbour, and was also engaged on works in connection with the water supply of Kirkintilloch and Lenzie. Mr. Lindsay entered the service of Messrs. Bell & Miller in 1874, and took part in the construction of Salterscroft Dock, the first graving dock to be built on the Clyde. He was also responsible for the design of the works at Newton of the Steel Company of Scotland, and for a time acted as manager of the workshops of the firm. He also planned the water supply of Grangemouth, Falkirk, and other towns, and superintended the carrying out of the work. Later he took a leading part in the planning of waterworks at Pelotas, and at Rio Grande do Sul, Brazil. Furthermore, Partick Bridge over the Kelvin, and Abbey and Abercorn Bridges in Paisley, were constructed to his design.

In 1880 Mr. Lindsay opened a consulting practice on his own account. As engineer-in-chief of the undertaking, and in collaboration with an architect, he designed and erected structures of steel, masonry, and wood, and planned the water and drainage systems and roads for the Edinburgh International Exhibition in 1886. His designs for the Glasgow Exhibition in 1887 won for him the premium offered by the Exhibition Committee. Later he became engineer in this

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country to the Municipality of Singapore, and a considerable number of bridges, suited to the peculiar local requirements, were erected to his design. He was also engaged for many years on works in connection with Singapore water supply, and subsequently designed bridges and other civil engineering works for Glasgow Corporation.

During the whole of his active life Mr. Lindsay devoted much of his spare time to the cause of technical education. He served for many years as secretary of the Mechanics Institution, Glasgow, which was reconstructed in 1879 as the College of Science and Arts. He relinquished his office some years prior to 1886, when this college became one of the constituent institutions of the Glasgow Technical College.

Mr. Lindsay joined the Institution as a Graduate in 1873, and became a member in 1876. He was a Member of Council for sessions 1880-82, 1885-87, 1889-91, 1897-99, and 1900-02, and a Vice-President for sessions 1882-85.

JOHN MACDONALD was born at Glasgow on 26th February, 1847, and was educated at the Normal School, Glasgow. He served his apprenticeship to engineering with Mr. J. Yuill, Glasgow, and thereafter went to the Canal Basin Foundry, remaining there for about 12 years. After this he began business on his own account as a consulting engineer, and later opened an engineering work at Pollokshaws, where he commenced the manufacture of water turbines. He maintained his interest in this business throughout the remainder of his life, and in more recent years engaged also in the manufacture of pneumatic tools. At the time of his death, which occurred on 6th November, 1926, he was managing director of Messrs. John MacDonald & Co. (Pneumatic Tools), Ltd., Pollokshaws.

Mr. MacDonald joined the Institution as a Graduate in 1883, and was elected a Member in 1899.

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JAMES WRIGHT MACFARLANE died at Cathcart, Glasgow, on 16th February, 1928. He was born at Woodside, near Coupar-Angus, on 31st July, 1848, and was educated at Newbigging and Woodside Schools, and the old Technical College, Glasgow. He served his apprenticeship as an engineer with Messrs. Alexander Chaplin & Co., Ltd., now at Govan, and later joined Messrs. R. Laidlaw & Son, pipe founders, Port-Dundas, for whom he carried out some important work in Russia in connection with the St. Petersburg water supply. He designed, erected, and put into operation the Lochburn Iron Works, Maryhill, in which concern he was a principal, and acted as manager for a period of years. Subsequently, he transferred his services to Messrs. Watson, Laidlaw & Co., Glasgow, and was ultimately a managing partner in this firm until he retired in 1907.

Mr. Macfarlane was the author of "Practical Notes on Pipe Founding," which, although first published in 1888, is still considered a standard work on this subject. He also produced and patented many inventions, particularly in connection with improvements to sugar machinery, and on 26th October, 1886, he read a paper before the Institution on "The Safety Governor."

Mr. Macfarlane joined the Institution as a Member in 1880.

ROBERT ALEXANDER MIDDLETON was born at Sunderland on 17th October, 1856. He was educated and served his apprenticeship in his native town, and afterwards joined the staff of Messrs. John Elder & Co. (now the Fairfield Shipbuilding and Engineering Co.), Govan, with whom he remained for 16 years, being successively chief draughtsman, assistant ship department manager, and naval architect. He was then employed, in a consultative capacity, by Messrs. Workman, Clark & Co., Belfast, in the construction of high-class mail and passenger ships, and was later with Messrs. Vickers, Son & Maxim, Ltd., Barrow-in-Furness, as master of works. While in business on his own account, Mr.

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Middleton designed and supervised the construction of vessels for the Australian, Canadian, and Brazilian services. For some years prior to his death, which took place at Benton, Newcastle-upon-Tyne, on 2nd November, 1927, he was on the surveying staff of Lloyd's Register of Shipping.

Mr. Middleton joined the Institution as a Graduate in 1882, and was elected a Member in 1890.

ALEXANDER SPENCE MILLAR, a son of Mr. William Millar, Greenock, and a director of the Grangemouth Dockyard Co., died at his home in Grangemouth on 21st August, 1928. He was born at Govan in 1881, and was educated at the Falkirk High School and Glasgow University. He began his career by serving an apprenticeship with the Dockyard Co. at Grangemouth. When the Greenock yard was opened he spent two or three years there, and then returned to Grangemouth to take charge of the company's offices. For the past 14 years he was a director of the company.

Mr. Millar joined the Institution as a Graduate in 1902, was elected an Associate Member in 1911, and a Member in 1920.

WILLIAM JOHN PERITON was born at Devonport on 28th January, 1863, and was educated locally. He entered the Royal Dockyard in 1877 as a shipwright apprentice, and after serving four years was appointed to assist Mr. R. E. Froude in the experimental and scientific research carried on at the experimental tank, Torquay. During the three years he was thus employed he gained valuable experience in ship design, and the relation of horse-power to speed as affected by form of ship and type of propeller. In 1884 he returned to the Devonport Dockyard, and for 15 months was engaged in the mould loft and drawing office. In the autumn of 1885 he left

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the Government service to take up an appointment as assistant manager with Fairfield Shipbuilding and Engineering Co., Ltd., Govan, and during his ten years with that company several important vessels were built for the Cunard Line, the Donald Currie Line, and the Pacific Steam Navigation Co. For the subsequent ten years he was in the service of Messrs. Harland & Wolff, Ltd., in various capacities, and for a time was manager of their South Yard. In 1905 he started business on his own account in Liverpool as a consulting engineer and naval architect.

In his youth Mr. Periton was an athlete of some distinction. He was also an enthusiastic Volunteer, and served in the Devon Rifles and 2nd Volunteer Battalion H.L.I., retiring from the latter in 1895 with the rank of Captain. He died at Liverpool, after a brief illness, on 20th August, 1928.

Mr. Periton joined the Institution as a Member in 1904.

Associate Members.

Yozo Hirai was born at Wakayama, Japan, on 26th September, 1890, and was educated at the Tokyo Nautical and Marine Engineering College. He served his apprenticeship at the Kure Naval Dockyard and Engine Works, and afterwards served for a time as a sea-going engineer on the Nippon Yusen Kaisha steamers. He attended the engineering classes at Glasgow University for two years, and then became professor of engineering at the Kobé Nautical and Marine Engineering College. His death took place at Mukogun, near Kobé, Japan, on 26th August, 1927.

Mr. Hirai joined the Institution as an Associate Member in 1924.

Randolph James Waddington Whyte was born at Greenock on 25th February, 1896, and was educated privately

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and at Kelvinside Academy and the Technical College, Glasgow. He served his apprenticeship in one of the subsidiary companies of Messrs. William Beardmore & Co., Ltd., and during the war served in the Naval Air Force and the Royal Air Force. At the time of his death he was carrying on a merchant's business in Glasgow. Early in life he showed an aptitude for engineering, and in 1910 was granted a wireless experimental license. At his home in Skelmorlie he had a private workshop, well equipped with various machines and electrical plant, where he spent most of his spare time in research work. He was accidentally drowned while bathing at Machrie, Islay, on 26th July, 1928.

Mr. Whyte joined the Institution as an Associate Member in 1920.

Associate.

ALEXANDER RICHARDSON, who was for many years one of the best-known technical journalists in Great Britain, died at his home in London on 30th March, 1928. He was born in Dumbarton on 27th March, 1864, and received his early training as a journalist in that burgh. For some years he was assistant commercial editor of the "Glasgow Herald," in which capacity he came into contact with the leading industrialists then on the Clyde. His home associations and environment gave him an opportunity for the intensive study of shipbuilding and engineering problems, and in 1888, as a result of contributions he had made to the paper, he was invited to join the editorial staff of "Engineering," a connection which lasted for more than 36 years. During that period he became successively assistant editor, joint editor, and, on the death of Dr. W. H. Maw, editor, as well as being for some time a managing director of the company owning the paper. He retired at the end of 1924, and in February of the following year became consulting editor of "Shipbuilding and Shipping Record" and "The Marine Engineer

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and Motorship Builder," positions which he held up to the time of his death.

In 1918 he was elected Member of Parliament for Gravesend in the Unionist interest, and retained his seat until 1923, when he retired. During his term of office he did considerable work on committees, and the Knighthood which he received in 1922 was largely in recognition of his work as a member of the Select Committee on Telephones.

He had been long associated with Lord Brassey in the production of "Brassey's Annual," and on the death of Lord Brassey in 1920 acquired the copyright, and continued this publication as joint editor with Mr. Archibald Hurd. The title was subsequently altered to "Brassey's Naval and Shipping Annual," and shortly before his death Sir Alexander had bought Mr. Hurd's interest, becoming sole proprietor. A prolific writer on the subject he had made his own, he was the author of "Two Centuries of Shipbuilding," dealing chiefly with the work of the Scott family, of Greenock, "The Evolution of the Parsons Steam Turbine," and "The Man Power of the Nation," as well as a large amount of work which was necessarily unsigned.

Sir Alexander joined the Institution as an Associate in 1914.

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